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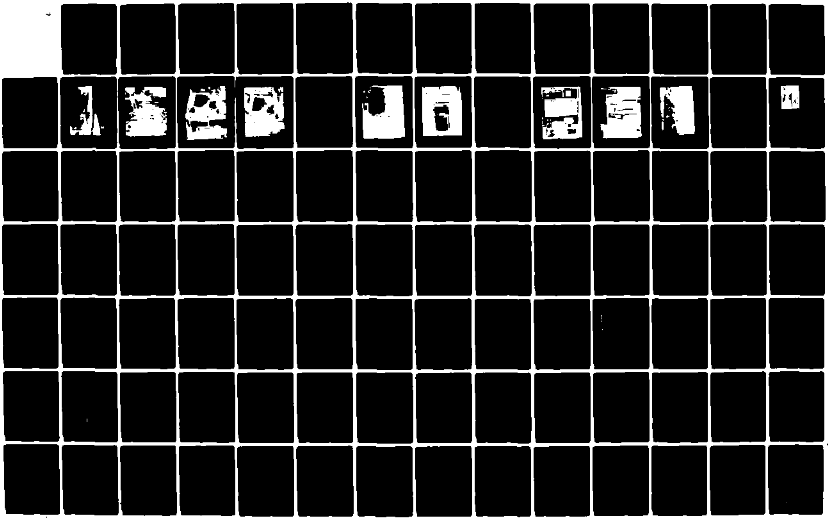

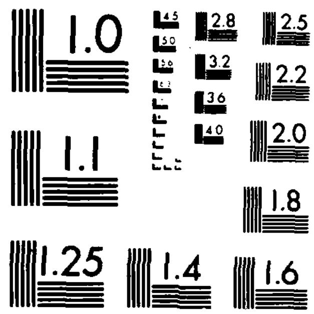

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Installation, Validation, and Flight Evaluation of the Federal Aviation Administration's Head-Up Display System

AD A138699

Federal Aviation Administration

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April 1983

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

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Technical Center
Atlantic City Airport, N.J. 08405

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16. Abstract

This report documents selected activities and results associated with the installation, validation, and flight evaluation of an FAA-owned Head-Up Display (HUD) research system as installed in a Boeing 727-100 FAA aircraft. Requisite installation, boresight, and flight validation activities, along with results obtained from a combined flight experience/flight evaluation exercise employing government pilots are presented. Pilot comments addressing HUD system performance, display symbology, control low responses, hardware implementation, and operational modes are addressed.

The HUD, a one-of-a-kind flightpath oriented research HUD, was evaluated in both an inertial (INS) referenced mode and an airmass (AM) referenced mode. Overwhelmingly, there was a strong preference for the INS referenced HUD mode.

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PREFACE

The Federal Aviation Administration (FAA), in conjunction with the National Aeronautics and Space Administration (NASA), established a joint Head-Up Display (HUD) Concept Evaluation Program to determine the contribution of a HUD to aviation safety in the approach and landing operations of jet transport category aircraft. This report documents selected activities as they pertain to the installation, boresight, validation, and flight evaluation of the FAA's HUD research system as installed in a Boeing 727-100 jet transport aircraft. This work was performed by personnel of the FAA, NASA, and the Boeing Commercial Airplane Company (BCAC) of Seattle, Washington.

The HUD Program Manager for this effort was LTC R. P. Neeland of ARD-340 of the FAA's Systems Research and Development Service. The FAA Technical Center's Program Manager was Mr. C. O. Masters of ACT-340 of the Aircraft Safety Development Division, and the FAA's HUD Simulation Program Manager was Mr. B. C. Scott of the FAA Engineering and Development Office located at the NASA-Ames Research Center.

The scope of this effort and the limited time frame in which it had to be accomplished demanded a devoted effort from the HUD team members and other support and advisory personnel. The following list summarizes the team members and support personnel, lists areas of responsibility, and is intended to recognize the important role and function performed by each.

NAME	ORGANIZATION	FUNCTION
A. Bazer	FAA, ACT-630	Chief HUD Project Pilot
D. Eldredge	FAA, ACT-340	Test Director
J. Gallagher	FAA, ACT-100	Systems Engineering
W. Lynn FAA,	FAA, ACT-340	HUD System Engineer
E. Pugacz FAA,	FAA, ACT-340	Instrumentation Engineer
J. Ryan FAA,	FAA, ACT-630	HUD Project Pilot
J. Jensen FAA,	FAA, ACT-630	Engineering Installation
W. Hansen FAA,	FAA, ACT-750	Data Reduction Support
D. Timateo FAA,	FAA, ACT-750	Data Reduction and Plots

A vital role was performed by Mr. Richard Bray of NASA's Ames Research Center, Moffett Field, California. Mr. Bray, the key developer of the symbology and control laws employed in this HUD system, provided timely and invaluable advice throughout the critical system checkout and validation phase, and assisted the HUD team in subsequent flight experience/evaluation activities.

Responsibility for the systems engineering and implementation of the HUD system, symbology, and control laws rested with the Crew System Technology Branch of BCAC. The efforts of the following Crew System Technology personnel are recognized:

NAME	FUNCTION
W. Smith	Chief, Crew System Technology
J. Kraus	HUD Project Leader
H. Sunahara	Lead Computer Systems and Software
R. Wilcox	Mechanical Engineering
S. Adkisson	Programming Support

The subject pilots fulfilled a crucial role during the flight experience/evaluation phase. These government pilots, all experienced test pilots (except one) and all transport category type rated, performed in a highly professional manner against a very demanding flight experience/flight evaluation schedule, and gave their utmost cooperation throughout the evaluation. They were:

NAME	ORGANIZATION
T. Anderson	FAA, ANW/S
L. Cusimano	FAA, AFO-210
R. Gough	FAA, AWS-160
G. Hardy	NASA-Ames
G. Lyddane	FAA, ANW/L
J. Martin	NASA-Ames
D. Melton	FAA, ANW/S
N. Moentman	FAA, ANW/L
L. Whallon	FAA, ANW/L.

Many sincere thanks are extended to each of these individuals whose contributions have helped to make this report possible.

LIST OF ABBREVIATIONS AND ACRONYMS

AC	Advisory Circular
A/C	Aircraft
ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
AGL	Above Ground Level
ALT REF	Altitude Reference
AM	Airmass
AOA	Angle-of-Attack
A/S	Airspeed
BCAC	Boeing Commercial Airplane Company
CAT-II	Category II
CAVU	Ceiling and Visibility Unlimited
CRT	Cathode Ray Tube
CTOL	Conventional Takeoff and Landing
DEU	Drive Electronics Unit
DG	Directional Gyro
DH	Decision Height
DME	Distance Measuring Equipment
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FIFO	Flight Inspection Field Office
FL	Flight Level
fpm	Feet Per Minute
FSAA	Flight Simulator for Advanced Aircraft
GS	Glide Slope
G/S	Groundspeed
HDD	Head-Down Display
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
IAF	Initial Approach Fix
IAS	Indicated Airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IVSI	Instantaneous Vertical Speed Indicator
LOC	Localizer
LTN-51	Litton 51 Inertial Navigation System

MA	Missed Approach
MAP	Missed Approach Point
MBTD	Miles Before Touch Down
MDA	Minimum Descent Altitude
MLS	Microwave Landing System
MM	Middle Marker
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
nmi	Nautical Mile
NPA	Non Precision Approach
OM	Outer Marker
PAR	Precision Approach Radar
PDU	Pilot's Display Unit
PGG	Programmable Graphics Generator
PIO	Pilot Induced Oscillation
PMCP	Pilot's Mode Control Panel
PROM	Programmable Read Only Memory
RAM	Random Access Memory
RMI	Remote Magnetic Indicator
Rwy	Runway
STOL	Short Takeoff and Landing
TO/GA	Takeoff/Go-Around
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
Vref	Target Airspeed
VG	Vertical Gyro
VOR	Very High Frequency Omnidirectional Range
V_R	Rotation Speed
V_1	Critical Engine Failure Speed
γ	Gamma (Flightpath Angle)

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EXECUTIVE SUMMARY

From April through June 1981, the Federal Aviation Administration's (FAA) Research Head-Up Display (HUD) system was installed in an FAA-owned Boeing 727-100 aircraft and flight validated at both the FAA Technical Center in Atlantic City Airport, New Jersey, and at the Boeing Commercial Aircraft Company (BCAC), Seattle, Washington. Following validation, a 2-week flight experience/evaluation effort was conducted at the National Aeronautics and Space Administration (NASA) Ames Research Center, Moffett Field, California. Seven FAA and two NASA test pilots were given initial training using the Ames Flight Simulator for Advanced Aircraft (FSAA) followed by hands-on experience with the HUD in the Boeing 727 aircraft. This HUD, a one-of-a-kind conformal flightpath oriented research system, could provide the pilot with either inertial referenced or airmass (AM) referenced flightpath information.

The nine pilots accumulated a total of 35 hours of flight time using the HUD for takeoff, en route, precision and nonprecision approaches during day, dusk and night operations in a variety of wind and turbulence environments. This report documents the observations made during the installation and validation phases, summarizes the pilot comments and data collected during the flight evaluations and identifies the modifications and corrections to the HUD system that should be accomplished before future work is attempted.

Some of the more significant observations resulting from these installations, validation, and flight experience/evaluation activities are:

1. High quality sensor data is essential for optimal performance of this type of HUD.

2. This HUD system did not exhibit any need for frequent boresight checks.

3. The subject pilots indicated a strong preference for the INS referenced HUD mode over the airmass referenced HUD mode.

4. The use of this HUD in all operational modes of the aircraft, i.e., takeoff, en route, terminal area maneuvering, approach, landing, and go-around met with pilot acceptance.

INTRODUCTION

PURPOSE.

The purpose of this report is to document selected activities and results associated with the installation, validation, and flight evaluation of the Federal Aviation Administration's (FAA) Head-Up Display (HUD) research system No. BCAC-ID-79-265 as installed in a Boeing 727-100 FAA aircraft. It is intended that this report provide information and substantiating data which may be of use to FAA regulatory personnel in the preparation of rules, procedures, advisory circulars (AC), and certification standards associated with the use of a HUD in derivative and new generation, large turbojet aircraft.

BACKGROUND

In 1977, a joint FAA/National Aeronautics and Space Administration (NASA) HUD Concept Evaluation Program was established in an effort to determine the contribution, if any, of a HUD to aviation safety in commercial jet transport approach and landing operations. To accomplish this, consideration was given not only to the possible benefits of a HUD but also to the possible limitations that may arise, and to any possible detrimental effects or hazards that a HUD might create in the operational environment (see reference 1 for details of program plan). The program was organized into four major phases: Phase I, for which the FAA had major responsibility, was a review of the relevant literature and an analysis of the major issues surrounding HUD. The results of this effort were published in reference 2.

The NASA-Ames Research Center had major responsibility for phase II of the program. This phase had two major objectives: (1) To evaluate certain fundamental human factor issues relating to the design and operation of HUD's; and (2) to develop candidate HUD concepts to be evaluated in phase III. These phase II laboratory and simulator experiments have been reported elsewhere, and a complete list of authors and titles is given in appendix A.

Phase III of the program consisted of a simulator evaluation using two different head-up display concepts as well as conventional head-down instruments under a variety of environmental and operational conditions to determine: (1) The potential benefits of these HUD's in airline operations; (2) problems which might be associated with their use; and (3) flight-crew training requirements and flight-crew operating procedures suitable for use with the HUD's. Results of the Phase III simulation evaluation effort are found in reference 3.

Phase IV consists primarily of the flight test program. This phase was an FAA responsibility with the following objectives:

1. Validate simulator and laboratory results in flight test.
2. Obtain operational experience with HUD.
3. Develop criteria to aid in formulation of certification standards.
4. Investigate advanced HUD concepts.

To accomplish these objectives, in June 1979 the FAA awarded a contract to the Boeing Commercial Airplane Company (BCAC) of Seattle, Washington, for the design, development, and system integration of a flight quality binocular electro-optical HUD system. This system, a one-of-a-kind research tool, was delivered and installed in the FAA's Boeing 727-100 aircraft stationed at the FAA Technical Center, Atlantic City Airport, New Jersey, during the period January to May 1981. A flight validation period followed and resulted in a verification of the operational performance capabilities of the HUD system concept, while identifying areas requiring corrections, modifications, or improvements. Some of these changes were completed at the FAA Technical Center; however, the majority were performed by BCAC in Seattle, Washington. This was followed by a 2-week operational experience/evaluation exercise conducted at the NASA-Ames Research Center, Moffett Field, California, in which FAA regional and headquarters pilots and selected NASA pilots were afforded the opportunity to acquire initial training on the NASA-Ames Flight Simulator for Advanced Aircraft (FSAA) and then given hands-on flight experience in the operation of the FAA's HUD equipped Boeing 727.

This report documents the results of the installation, validation, flight validation, and flight evaluation activities as they pertain to the FAA's HUD system.

DESCRIPTION OF EQUIPMENT

TEST AIRCRAFT.

The aircraft used in this evaluation was an FAA Boeing 727-100 series turbojet transport (figure 1). The Boeing 727 constitutes a large portion of the current aircarrier service fleet and is expected to continue in airline service in significant numbers well into the 1990's. The test aircraft utilized a nominal operating weight of 140,000 pounds and was configured to accommodate 20 passenger seats in the aft section of the cabin, with the rest of the palletized cabin floor area being used to house project equipment and instrumentation. Avionics onboard included dual inertial navigation systems (INS), dual VHF NAV receivers with glide slope, dual DME's, a marker beacon receiver, an ADF receiver, an autopilot, flight directors, a radio altimeter, dual air data computer systems, and dual HSI's and ADI's.

HEAD-UP DISPLAY EQUIPMENT.

HUD equipment was installed in both the cockpit area and in the forward cabin area of the aircraft. The equipment installed in the cockpit area included a Pilot's Display Unit (PDU), a Drive Electronics Unit (DEU), a Pilot's Mode Control Panel (PMCP), a pilot's declutter switch, and a safety pilot's monitor. These are described in the following paragraphs.

Pilot's Display Unit - The Pilot's Display Unit (PDU) (figure 2) manufactured by Sundstrand, Incorporated, consists of a combiner plate, Cathode-Ray Tube (CRT), relay optics, and supplemental electronics which present to the pilot a cursive display of the HUD symbology as determined by X, Y, and Z input signals from the Programmable Graphics Generator (PGG). In its operating position (figure 3), the plane of the acrylic block (combiner plate) is positioned approximately 6 inches in front of the pilot's eyes. In the stowed position (figure 4), it fits nearly flush in the overhead eyebrow window cavity with negligible restriction to pilot's outside view. It is hinged to allow for forward motion, with the breakaway force of 3 pounds from its detent. The principal characteristics of the PDU are listed below:

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FIGURE 1. THE FAA'S BOEING 727-100 HUD TEST BED AIRCRAFT

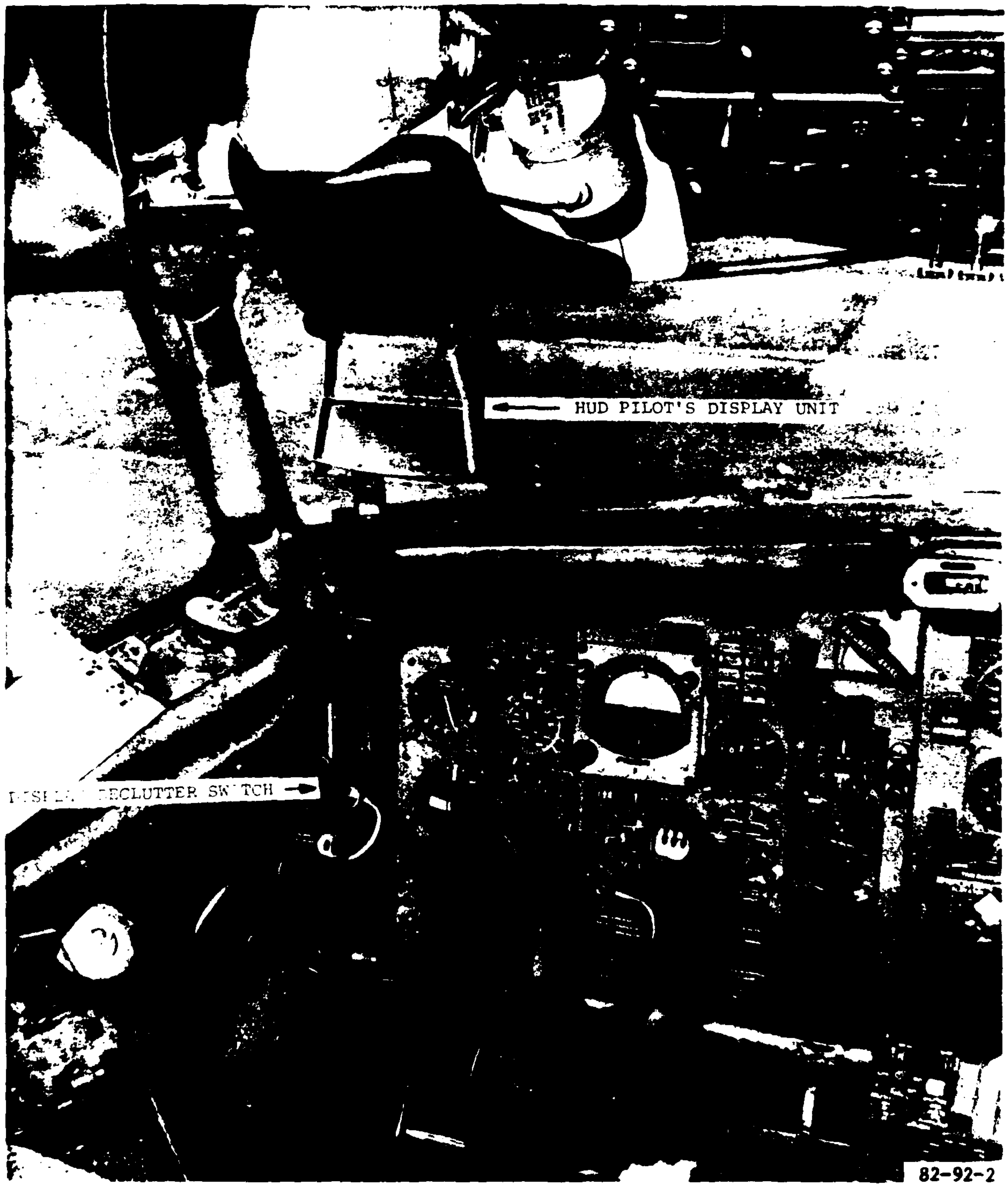

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FIGURE 2. BOEING'S 727-100 COCKPIT AREA SHOWING HUD PILOT'S DISPLAY UNIT AND DISPLAY DECLUTTER SWITCH

FIGURE 3. HUD PILOT'S DISPLAY UNIT IN OPERATING POSITION

FIGURE 4. HUD PILOT'S DISPLAY UNIT IN STOWED POSITION

Size	Contoured to fit the cockpit location, the overall size is 11.1 inches wide, 14.8 inches long, and 7.6 inches deep.
Weight	18 pounds
Power	115V ac, 400 Hz, 1-phase, 150 VA
Field of View	Vertical - 26°; Horizontal - 30°
Collimation	Infinity

Drive Electronics Unit - The Drive Electronics Unit (DEU) (figure 5) contains all the electronics required to receive the X, Y, and Z signals from the PGG and drive the PDU, including deflection amplifiers, linearity correction circuits, brightness control circuits, phosphor protection, and a low-voltage power supply. The DEU controls consist of toggle switches for power ON/OFF and video test and a brightness control rheostat. The principal characteristics of the DEU are listed below:

Size	The DEU will fit standard panel racks. Overall dimensions are 7.5 inches high, 5 inches deep, and 5.76 inches wide.
Weight	Approximately 6.5 pounds
Power	28V dc approximately 60 W
Mounting	The DEU fits in the center overhead panel in the cockpit.

Pilot's Mode Control Panel - The Pilot's Mode Control Panel (PMCP) is the pilot's main controlling device for the HUD system and provides the pilot and/or copilot with the capability to select the various HUD flight modes. This unit was installed on the right side of the radar subpanel so as to be within reach of either pilot; however, during the flight tests, it was operated by the safety pilot. The activation of operational modes are effected through the selection of the appropriate pushbutton switch, while the input of variables such as runway elevation, magnetic variation, airspeed reference, etc., are via toggle switches and are displayed on a 5-digit segmented light readout. An illustration of the PMCP and a discussion of operational modes are included in appendix B.

Safety Pilot's Monitor - The safety pilot's monitor (figure 6) consisted of a miniature Tektronix Model 221 oscilloscope which was adapted to display a miniaturized version of the symbology as presented on the PDU. It was mounted beneath the copilot's glare shield so as not to obstruct the view of cockpit instrumentation. Its display dimensions were 5.0 cm wide by 3.0 cm high.

Pilot's Declutter Switch - This thumb operated switch (figure 2) is mounted on the left side of the pilot's control wheel, and is used for declutter and blanking of HUD symbology in each of the flight modes. Operation of the declutter switch allowed the pilot to select one of three symbology display modes: (1) full display of symbology; (2) a declutter version; and (3) blanking of all symbology. Operation of the declutter switch was cyclic, in that three operations of the switch returns the displayed symbology to its original mode. The symbol schedule delineates the symbols which are displayed for each mode (appendix C).

The HUD equipment installed in the cabin area of the Boeing 727 consists of three major subsystems which are described in the following paragraphs:

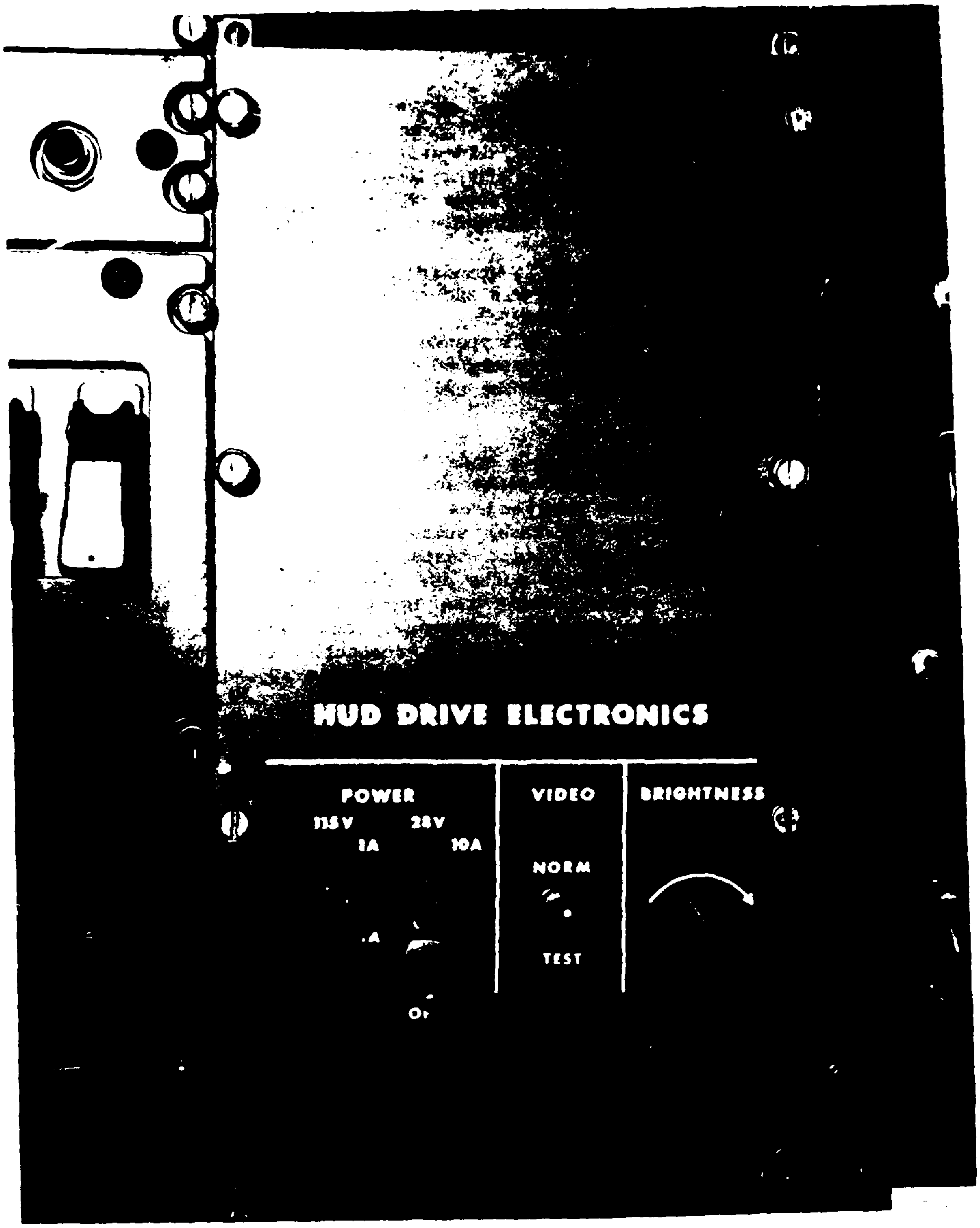

FIGURE 5. HUD DRIVE ELECTRONICS UNIT MOUNTED IN OVERHEAD PANEL

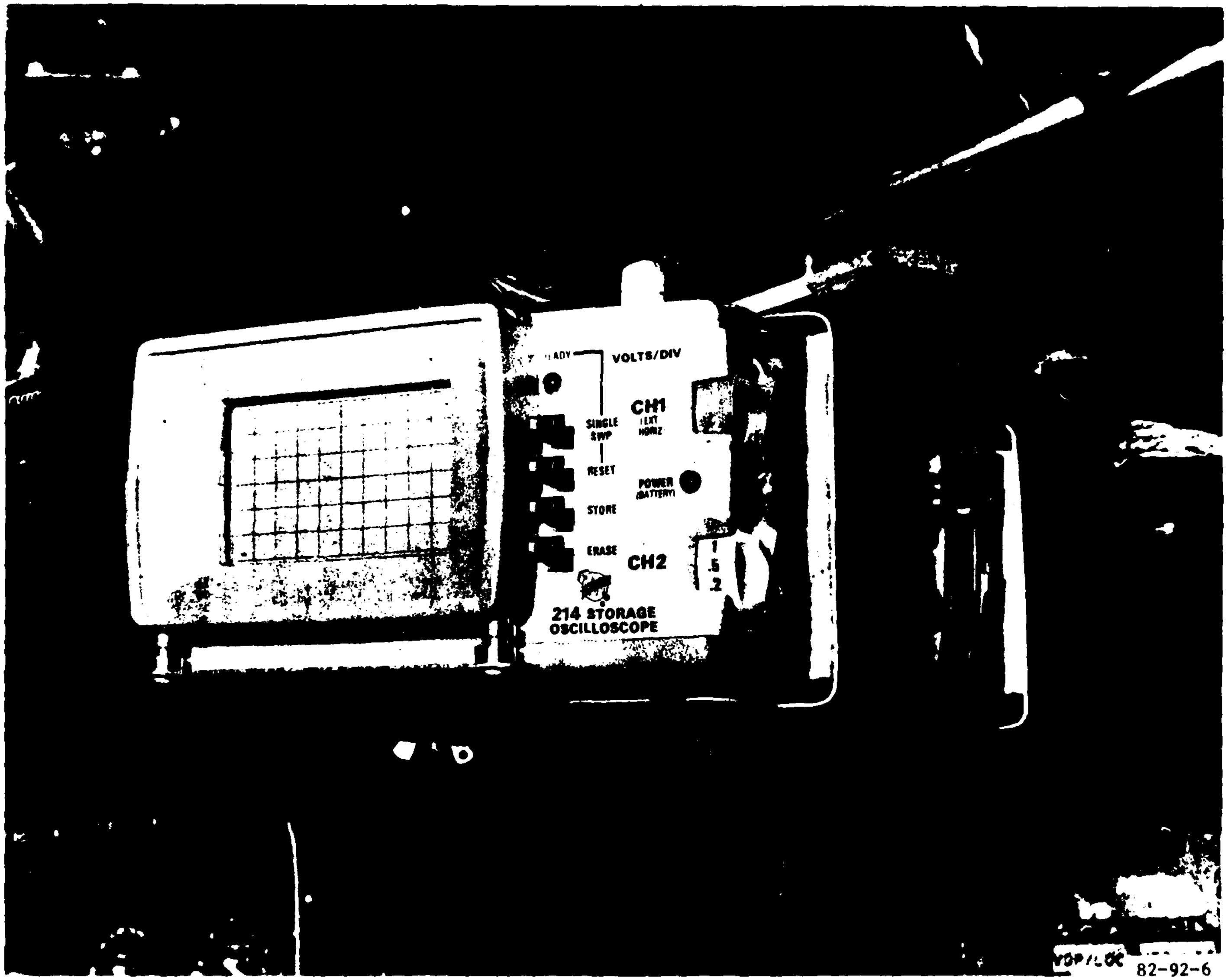

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FIGURE 6. SAFETY PILOT'S MONITOR/SCOPE MOUNTED BENEATH COCKPIT GLARE SHIELD

Programmable Graphics Generator - This unit (figure 7) manufactured by Smith Industries, Incorporated, generates and calculates the positions of the display symbology which is ultimately presented by the pilot's display unit. Functionally, it is partitioned into three sections: a dual graphics generator, a microcontroller, and an interface section. The dual graphics generator develops display symbology such as vectors, arcs, circles, and characters, and also performs character rotation and translation. The microcontroller accepts aircraft input data from the CONRAC interface unit in MIL-STD-1553 format, performs the necessary scaling, symbol selection, and display formatting tasks, and outputs to the graphics generator. The interface facilitates multilevel communication with external systems including RS-232 inputs from the interactive control unit and the PGG's attached paper tape reader. A 9511 arithmetic processor was added to the basic system; however, no significant improvement in trignometric or logarithmic computation speed was noted.

CONRAC Interface Unit - This equipment serves as the interface link between the aircraft sensors and the PGG. It receives aircraft sensor information in analog, synchro, and digital form, along with other discrete signals, and converts them to MIL-STD-1553 high speed serial digital data format for use by the PGG. The heart of this unit is an 8086 16-bit microprocessor and external operator control over its functioning is not possible.

Interactive Controller - This unit is called the Test Conductor's Panel and is the primary HUD engineering/operator interface (figure 8). It provided the capability to individually delete most HUD symbology from the display while enabling the selection of several different algorithms to compute flightpath and flightpath acceleration. Also, it displayed sensor failure information and when control is relinquished by the pilot's mode control panel, it performed the functions of the PMCP.

There are several ancillary units which constitute part of the HUD system. These include a conventional X-Y oscilloscope display (also called the remote monitor, figure 8) which presents the same symbology that is presented on the pilot display unit, a logic analyzer that monitors the 1553 data bus between the CONRAC Interface Unit and the PGG, and a paper tape reader and keypad/display panel (mounted on the PGG) which are used in software development.

HEAD-UP DISPLAY FORMAT.

The basis for the head-up display symbology and control laws implemented in the FAA HUD Research System were developed and documented by R. S. Bray at NASA-Ames Research Center as part of the NASA/FAA Head-Up Display Program (reference 4). Initially, this display format was intended to provide flight guidance and navigation information for approach, landing, and go-around operations. However, the format was modified for this program to include information for takeoff, terminal area maneuvering, and en route operations. Figure 9 depicts portions of the HUD symbology as viewed through the PDU during a validation flight. The display is representative of that category of HUD formats that include attitude and navigation symbology elements scaled to overlay the outside scene references. Displays of this type are often referred to as "conformal." The primary element of the display, an element which is directly controlled to appropriate display or visual scene references by rolling and pitching the aircraft, is the "winged" circle which indicates the instantaneous direction of the airplane's flightpath relative to inertial (earth-related) references. Associated with this symbol are indications of altitude, airspeed, and acceleration along the flightpath. In VMC, in the absence of Instrument Landing System (ILS) guidance, the conformal elements, together with the flightpath indication, provide the means for explicit approach

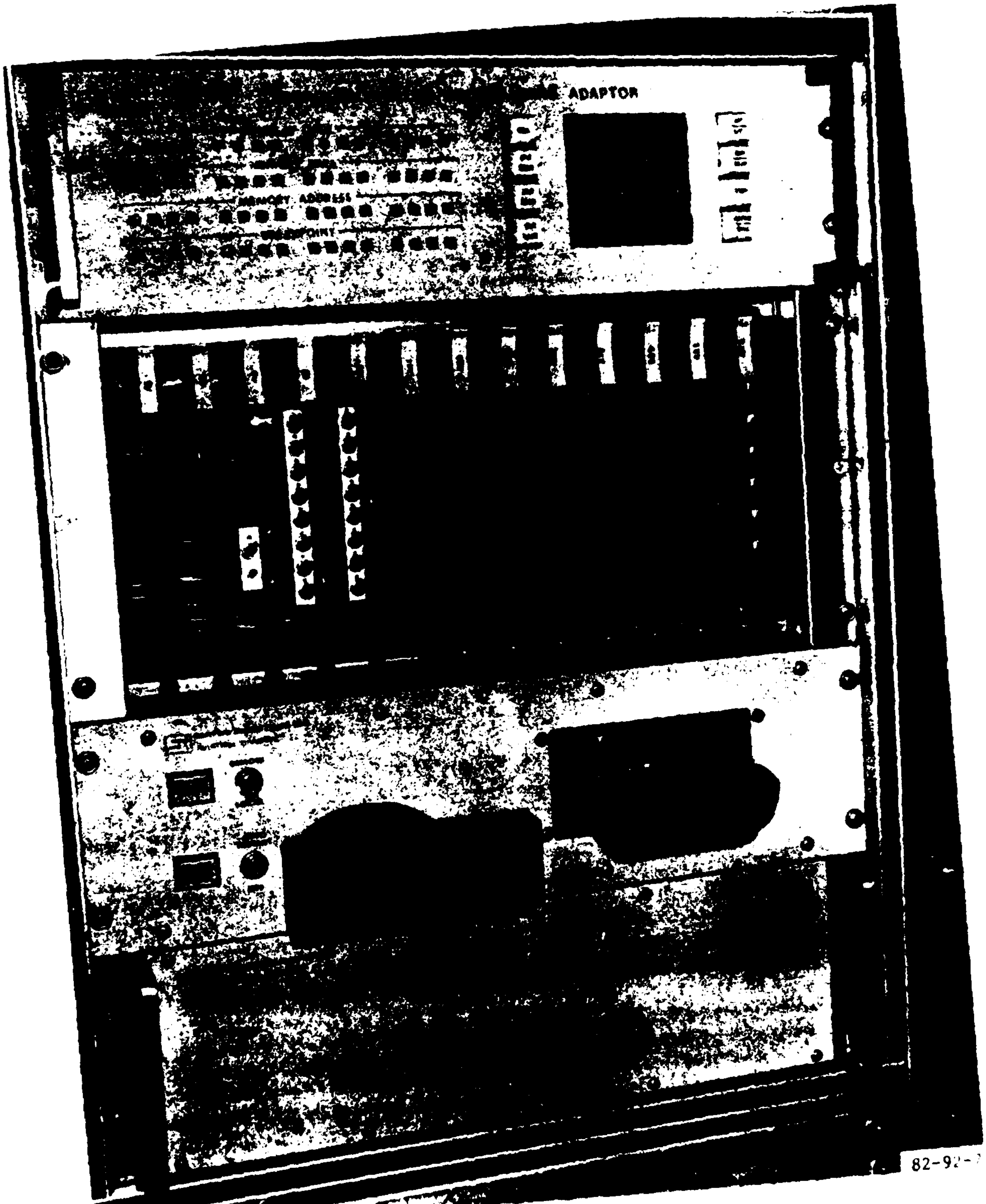


FIGURE 7. PROGRAMMABLE GRAPHICS GENERATOR (FRONT COVER REMOVED)

FIGURE 8. HUD RACK MOUNTED EQUIPMENT SHOWING TEST CONDUCTOR PANEL, INTERACTIVE CONTROLLER, AND REMOTE MONITOR

FIGURE 9. HUD SYMBOLOGY AS VIEWED THROUGH THE PILOT'S DISPLAY UNIT

path guidance, with a precision dependent upon the accuracy of the attitude and inertial velocity sensors aboard the airplane. In Instrument Meteorological Conditions (IMC), ILS error signals are utilized in the presentation of approach guidance references to which the flightpath can be "flown." In figure 9, the aircraft is at an altitude of 2,490 feet mean sea level (m.s.l.), an airspeed of 196 knots, level flight, 5-degree pitch attitude, heading of 316 degrees, and a speed error of approximately 8 knots below target airspeed.

To be most effective, the conformal flightpath display concept demands a high level of precision of attitude sensing, and means for sensing or approximating inertial velocities. As detailed later, the aircraft was equipped with dual LTN-51 inertial navigation systems, which were the primary source of attitude and inertial velocity signals for the display. Although configured to take advantage of these high precision inertial sensors, the format was also flown in an "airmass" mode that assumed the unavailability of the inertial platforms. Attitude signals were obtained from the standard gyro systems in the aircraft and flightpath measures were those relative to the atmosphere. A detailed description of the HUD display format is contained in appendix D.

SIMULATION FACILITIES.

The simulation facilities and model used in this program are described in the following paragraphs:

Mathematical Model - The basic mathematical model used represented a typical production configuration of the Boeing 727-200 airplane with JT8D-7 engines. This model had been purchased from the BCAC for use in previous simulations. Configurations and flight conditions for this experiment were limited to approach and landing operations.

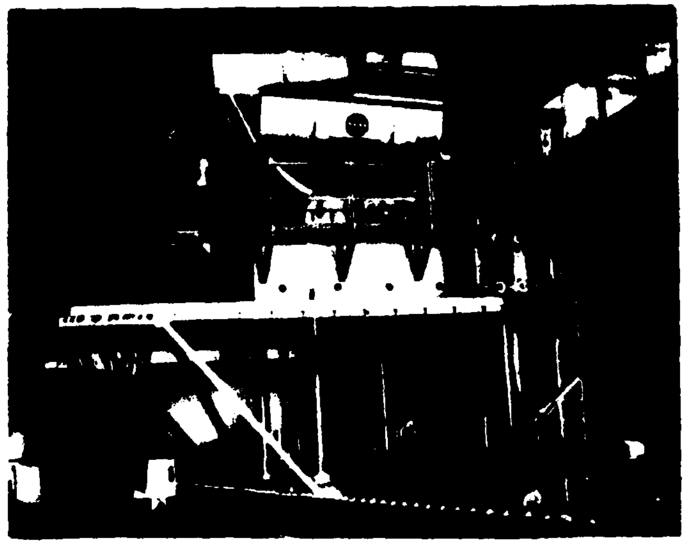
Simulator Apparatus - The entire simulation part of the program was carried out on the NASA-Ames Research Center's FSAA equipped with the Redifon TV model-board visual-display system. The FSAA is a general purpose aircraft simulator that was designed for general piloted aircraft simulations. The motion system is a six degree-of-freedom device designed to impart rotational and large-amplitude translational movement to the cockpit. A photograph of the simulator area containing the motion system and cockpit is shown in figure 10.

The Redifon visual display was a crucial element of the simulator system. In the Redifon system, the visual image of the outside world is presented to the pilot by a color-television system, whereby a camera looks at a model in the same way that the aircraft moves relative to the real-world, and a dynamic image of the outside world is created. A monitor placed before the pilot displays this scene through a collimating lens system that focuses the image at optical infinity.

The area of primary concern on the terrain model board contains a conventional airport with runway dimensions of 200 x 8000 feet and a Category II ILS lighting system. Also, a limited-visibility simulation device is incorporated in the television electronics; the simulation represents visibility conditions just under a low overcast, where objects on the ground (approaching the horizon) become less distinct until, at some elevation angle the contrast is zero and no objects are visible. This capability can also be programmed as a function of distance to create variable visibility conditions. For this simulation, the cab was configured

FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA)

AMES RESEARCH CENTER



PRIMARY PURPOSE:
- LANDING, TAKEOFF & HANDLING QUALITIES INVESTIGATIONS
- CREW TASK EVALUATIONS

KEY CHARACTERISTICS:
- 3 MAN COCKPIT
- 6 DEGREE FREEDOM
- ·50 FT. LATERAL TRAVEL
- PANEL, CENTER & OVERHEAD INSTRUMENTS
- IMAGE TV DISPLAY
- AIRCRAFT SOUND GENERATOR
- DIGITAL COMPUTER

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FIGURE 10. NASA'S FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA)

to be generally representative of a Boeing 727 aircraft with the captain's station having a complete set of fully functional instruments. The center panel contained a full set of engine instruments, the flap indicators, and the landing-gear handle and indicating lights. The center console contained the throttles, spoiler handle, flap handle, and flight-director mode select panel.

HUD Display Generation - Since actual HUD hardware was not available, the symbology for the HUD was generated by a graphics display computer and displayed on a CRT. This image is reformed at optical infinity by two planoconvex lenses mounted before the pilot. A beamsplitter, oriented at 45° between the lens and the monitors, permits the pilot to view the HUD and the outside-visual-scene display, simultaneously. The actual HUD CRT is mounted above the cockpit and its optical axis is at 90° to the line-of-sight. A schematic view of the lenses and beamsplitter is shown in figure 11.

The maximum field of view that could be provided was 24° wide by 18° high; the limiting factor was the size of the CRT on which the HUD image was displayed. Also, to add realism, a mockup of a HUD combiner plate was mounted on the overhead panel with a hinge mechanism which allowed it to be either stowed out of sight or locked approximately 6 inches in front of the pilot's eyes. The pilots were asked to adjust their seat position so that they viewed the display image through the combiner plate.

INSTRUMENTATION.

Digital Data Collection System - The airborne data collection system utilizes a ruggedized minicomputer which is equipped with 32 kilowords of programmable memory, floating point arithmetic hardware, floppy disc controller, RS-232 serial line interface, and a programmable real time clock. An FAA Technical Center fabricated aircraft systems coupler takes aircraft sensor data in analog, synchro, serial digital, and discrete form and converts it into a format compatible with the computer's internal data bus. It also interfaces a time code generator with the minicomputer system. Dual ruggedized floppy disc drives are used to store and transport the data collection software. The airborne data is collected every 100 milliseconds and recorded every second on a 9-track, 800 bits per inch digital magnetic tape transport. A ruggedized graphics terminal provides user interaction and real-time data display in engineering units in pseudo strip chart form. Also a hard copy unit provides dry-silver process recordings of any parameter displayed on the graphics terminal. The time code generator is capable of being synchronized to an external time source, for aircraft tracking purposes. A list of recorded parameters is shown in table 1.

Video Recording System - Video recording of HUD symbology generated by the programmable graphics generator were made for each flight. The video recording system consisted of a color TV camera, power supply, camera control unit, and a video recorder/player. The camera was installed and oriented to record the HUD display symbology which appeared on a remote monitor in the cabin area of the aircraft. Outputs from the ships internal intercom and data from the time code generator in IRIG-B format were recorded on the audio channels of the video recording system.

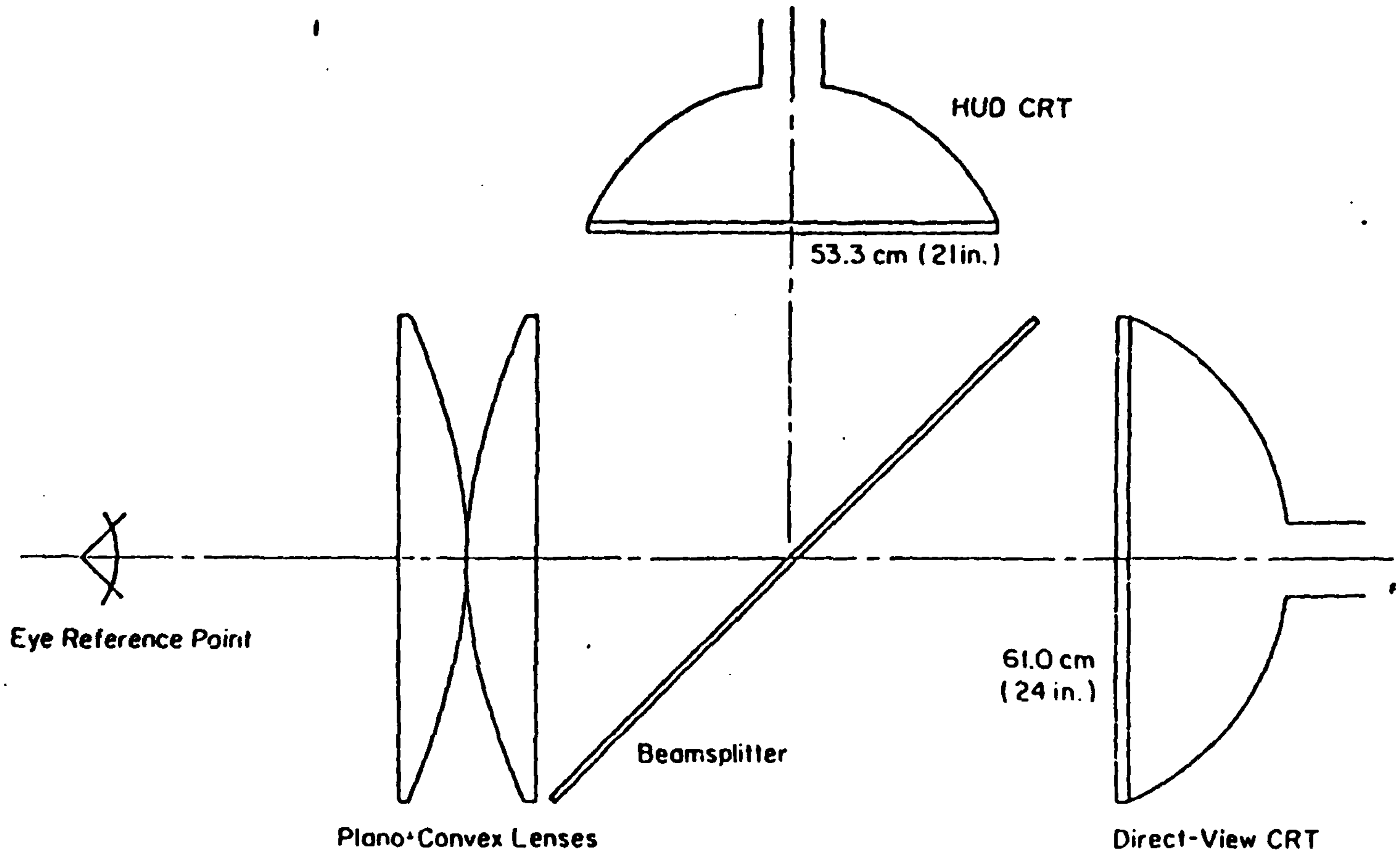

FIGURE 11. SCHEMATIC VIEW OF FSAA HUD LENSES AND BEAMSPLITTER

TABLE 1. RECORDED AIRBORNE PARAMETERS

PARAMETER	INPUT SIGNAL FORMAT	RANGE	RESOLUTION	INPUT DATA RATE	SIGNAL SOURCE
Glide Slope Deviation	Analog DC	± 150 ua	0.5 ua	*	#1 Nav. Receiver
Localizer Deviation	Analog DC	± 150 ua	0.5 ua	*	#1 Nav. Receiver
Radio Altitude	Analog DC	-10 to 3001 ft.	1 ft.	*	Radio Altimeter
Pitch	Synchro	± 180°	.02°	*	#1 LTN-51 Inertial Navigation System (INS)
Roll	Synchro	± 180°	.02°	*	#1 INS
Ground Speed	Serial Digital	0-3276.7 kts.	0.1 kt.	0.6 Hz	#1 INS
True Heading	Serial Digital	0-360°		0.6 Hz	#1 INS
Ground Track	Serial Digital	0-360°		0.6 Hz	#1 INS
Baro Corrected Altitude	Dual Synchro	-1000 to 50,000 ft.	1 ft.	*	Pilot's Altimeter
Drift Angle	Synchro	± 180°	.02°	0.6 Hz	#1 INS
True Airspeed	Serial Digital	130 to 599 kts.	1.0 kt.	2 Hz	Sperry Digital Central Air Data Computer (CADC)
Computed Airspeed	Serial Digital	30 to 450 kts.	.25 kts.	8 Hz	Sperry CADC
Pressure Altitude	Serial Digital	-1000 to 50,000 ft.	1.0 ft.	*	Sperry CADC
Altitude Rate	Serial Digital	± 20,000 ft/min.	20 ft/min.	*	Sperry CADC
DME Distance	Serial Digital	0-399 nmi	.01 nmi	*	#1 DME Interrogator

*Input data rate spec does not apply to analog signals, or input rate higher than recording rate

INSTALLATION PHASE

EQUIPMENT.

The HUD equipment was installed in two general areas of the aircraft; namely, the cockpit area and the forward cabin area. The equipment installed in the cockpit area (i.e., PDU, DEU, PMCP, and display declutter switch) are representative of equipment that would be installed in operational type transport aircraft. The safety pilot's display monitor installed beneath the copilot's glare shield is not considered representative of future HUD installations since its function would be accomplished by a second HUD for the copilot during typical air carrier operations. The following paragraphs will describe the installation process and the electronic cabling/interconnection requirements for each piece of equipment.

Pilot's Display Unit - This unit was installed to facilitate a nominal viewing distance of 6.25 inches between the pilot's eye position and the combiner lens. It was mounted to an adapter bracket which, in turn, was mounted to a cast aluminum window blank that replaced the outboard eyebrow window. All hardware was contractor provided and had been fitted prior to delivery. Replacement of the window panel required shimming and standard sealing techniques, and the window heat wires had to be capped and stowed. The bracket attachment to the window blank was routine; however, the display unit required considerable manipulation in order to effect alignment with existing screw holes in the bracket. The display was secured to the adapter bracket with three fasteners for easy removal. Installation of electrical power was conventional.

Drive Electronics Unit - This unit, originally designed to fit in a center overhead cockpit panel, required considerable overhead panel space for installation in close proximity to the PDU. It contains the electronics required to receive the video signals from the PGG and drive the PDU. These electronics include deflection amplifiers, brightness control circuits, phosphor protection, linear correction circuits, and a low voltage power supply. Consequently, considerable cooling was required to dissipate approximately 60 watts of consumed power. In cooling, it drew conditioned air from the cockpit area and exhausted it to an overhead void space where it was vacated by the air return system. Installation in the overhead panel was standard, with the unit being held in place by six dzus fasteners. In newer models of this display unit, the PDU and DEU functions have been combined into a single unit.

Pilot's Mode Control Panel - This unit, installed on the right side of the radar subpanel, required 7 inches of standard control panel space. It is secured in place by 8 dzus fasteners, thus requiring no special installation procedures or hardware. Connection of the 28V d.c. electrical power was conventional.

Pilot's Declutter Switch - This switch, a momentary pushbutton normally open device, was mounted to the left side of the pilot's control wheel via conventional bracketry and screws. Its connection to signal cabling was conventional. No electrical power connections were required.

Electronic Interconnections - Interconnection of the HUD system components was accomplished using standard No. 22 or larger aircraft signal wires in wiring harnesses and cables. Special shielded cables and twisted pair shielded cables were required between the DEU and the PDU to accommodate the X-yoke, Y-yoke, and Z-grid drives inputs. Interconnection of the PGG and the CONRAC unit via the MIL-STD-1553 data bus required special twisted-shielded pair wire, with special precautions being taken to ensure proper grounding of the shield. The X, Y, and Z video signals from the PGG to the DEU and monitors were accommodated via standard 75 ohm coaxial cable. To facilitate removal and installation of the HUD components, all sensor inputs were first routed to a project test panel so as to require only plug connections to the HUD system input; e.g., the CONRAC Interface Unit. Grounding straps were routed between all equipments. Interconnecting cables were routed in cable trunks and behind panels in accordance with standard practice.

BORESIGHT.

Following the completion of the initial HUD installation in January 1981, an installation boresight and scaling check was performed in accordance with procedure specified in BCAC document No. DG-49679TN (appendix E). In essence, this procedure required that the aircraft be located on a suitable hard stand, jacked and leveled, and that a suitable target board be fabricated for use in the boresight and scaling adjustments. A surveying crew, utilizing engineering transits, range finders, and tapes was required to survey the location of the target board, stanchions and other ground reference points in relation to fixed references/points on the aircraft. Boresighting was accomplished using initial mechanical adjustments to the PDU mounting bracketry, followed by fine adjustments of the "X" and "Y" potentiometers located in the DEU. Fine adjustments were then performed to remove curvature effects from lines and symbology near the display extremes via DEU circuit board adjustments. Also, scaling checks and adjustments to the horizontal and vertical scales were accomplished through the DEU. The initial boresight and scaling adjustments were accomplished in one day; however, this time was several hours longer than normal due to inclement weather. Following two checkout flights, the PDU and DEU were subsequently removed and returned to BCAC in late January 1981.

In May 1981, these units were reinstalled in the aircraft and a boresight recheck performed. This recheck indicated almost no perceivable change in vertical, horizontal, or roll alignment. However, a very small (1 to 2 linewidth) adjustment to the "X" and "Y" potentiometers was required; i.e., "X" -left and "Y" -up. Thus, the boresight remained appreciably the same over the 5-month period and indicated no requirements for frequent boresight checks. Scaling rechecks were performed at 50 feet either side of the center of the target board at a distance of 300 feet. A 0.5 degree discrepancy (9.0° versus 9.5°) was observed. Adjustments to the horizontal scaling circuitry was deemed unnecessary since the discrepancy occurred at the extremes of the display and was attributed to pincushioning effects. During subsequent validation and flight tests, no perceivable deviations in boresight or scaling accuracies were observed.

FLIGHT VALIDATION PHASE

The flight validation phase consisted of 21 flights conducted between May 8 and June 13, 1981, from the FAA Technical Center, Atlantic City Airport, New Jersey, and Boeing Field, Seattle, Washington. Tests were performed in accordance with the Technical Center's flight test plan (reference 5). All validation flights were performed by the FAA Technical Center project pilots. The overall objectives of the validation flight tests were as follows:

1. Check the aircraft installation for satisfactory system performance of both HUD system hardware and software.

2. Assess the validity of the HUD symbology and control laws.

3. Obtain baseline data for comparison of onboard sensor performance with external tracking references.

4. Verify operational suitability of supporting systems; e.g., airborne instrumentation, data collection system, etc.

5. Determine recommended modifications and/or corrections to be incorporated into the HUD system prior to the subsequent operational experience/flight evaluation exercise so as to effect better pilot/aircraft HUD system compatibility and performance.

FLIGHT VALIDATION AT THE FAA TECHNICAL CENTER.

During the period from May 8 to June 4, 1981, 15 validation flights were flown. The first six flights, encompassing approximately 14 flight hours, were devoted primarily to identifying incorrect system operations, debugging, and performing necessary software changes. A no-go condition existed if this test was not satisfactorily completed. During these flights, basic HUD control laws software and input/output (I/O) software were stored in random access memory (RAM) to facilitate software changes.

It should be noted that isolating and determining the source of flightpath errors, which use attitude, velocity, and acceleration inputs, is difficult in that improper responses can readily be attributed to a number of sources such as improper software implementation, incorrect control laws, malfunctioning sensors, etc.

The remaining validation flights conducted at the Technical Center were accomplished with the HUD software programs stored in programmable read only memory (PROM) and were geared toward further examination of the HUD system performance, symbology suitability, display characteristics, verification of modifications to onboard instrumentation, and the collection of baseline data. Flights were conducted in all modes and during day and night conditions. As experience was gained during day visual flight rules (VFR) flights, subsequent day IFR and finally night IFR flights were conducted with ceilings as low as 400 feet. As a result of these validation flights, a number of required changes, modifications, and/or corrections to the HUD system were identified for implementation at BCAC prior to the flight experience/ evaluation phase.

EN ROUTE MODE EXPERIMENTATION.

On Saturday, June 6, 1981, the HUD test bed aircraft and test team departed the FAA Technical Center en route to BCAC, Seattle, Washington, with an intermediate stop at Fargo, North Dakota. During this flight which lasted 5.8 hours, experimentation using the HUD in en route flight was performed. Jet airways were flown exclusively and the HUD system was operated in the IMC mode with VOR guidance. The aircraft was maintained on the airway centerline by keeping the localizer/VOR guidance symbol centered with respect to the selected course.

Drift angle corrections were readily apparent by observing the lateral offset between the aircraft reference symbol (heading) and the flightpath symbol.

The project pilots used the HUD during the entire trip and experienced no difficulties in using the HUD in this manner. They indicated that at this level of their experience there was no tendency to fixate on the displayed symbology and in fact, indicated that their exterior scan was quite good and on several occasions readily spotted other aircraft flying the jet airways. Also, neither pilot experienced any eye discomfort or strain from utilizing the HUD for such an extended period of time.

Subsequently, an automatic HUD en route mode was defined. Changes in the displayed symbology for this automatic mode are based primarily upon airspeed and altitude values and are discussed elsewhere in the report. Representative en route HUD symbology for altitudes above 15,000 feet m.s.l. is shown in figure 12.

FLIGHT VALIDATION AT BCAC.

Following arrival at BCAC, final modifications and corrections identified during the validation flights were implemented. Additional validation flights were conducted as necessary. One of these flights was of particular interest because the aircraft received a direct lightning strike. The strike was severe enough to cause several aircraft systems to malfunction, however, the HUD system experienced no effects. On June 13, 1981, the test aircraft departed BCAC for NASA Ames Research Center, Moffett Field, California.

Summary of Results of Installation and Flight Validation Phases - At this point, it is important to summarize the finding of both the installation exercise and all of the flight validation activities. The intent of this section is to identify what problem areas were encountered, discuss what was done to correct them, and to provide the reader with a more clear understanding of the HUD system evaluated in the next phase including an assessment of its limitations by the project team. The authors strongly recommend that the reader study the material in appendices B and D before continuing.

"Hardware" Elements of the System - In this section, discussion will be limited to findings related to the hardware items in the system.

Pilot Display Unit - Overall, the performance of the PDU was very acceptable with the recognition that mounting convenience considerations very slightly compromised the optimum positioning of the unit. The alignment stability and basic optical characterisitcs were good except that operation in high ambient light conditions identified the need for an improved contrast capability in that high intensity settings would cause the displayed symbology to bloom. Also, operations in and out of clouds and other atmospheric medium of varying light intensities indicated that an automatic contrast control might be desirable. "Mechanical" neutral-density filters for the forward face of the optical block appear to cope well with the high-brightness flight environments.

Pilot Mode Control Panel - Interactive Controller - Symbology configuration control by means of the interactive controller was generally satisfactory. All of the available functions performed as advertised. However, the functions of the PMCP and its counterpart associated with the interactive controller at the test

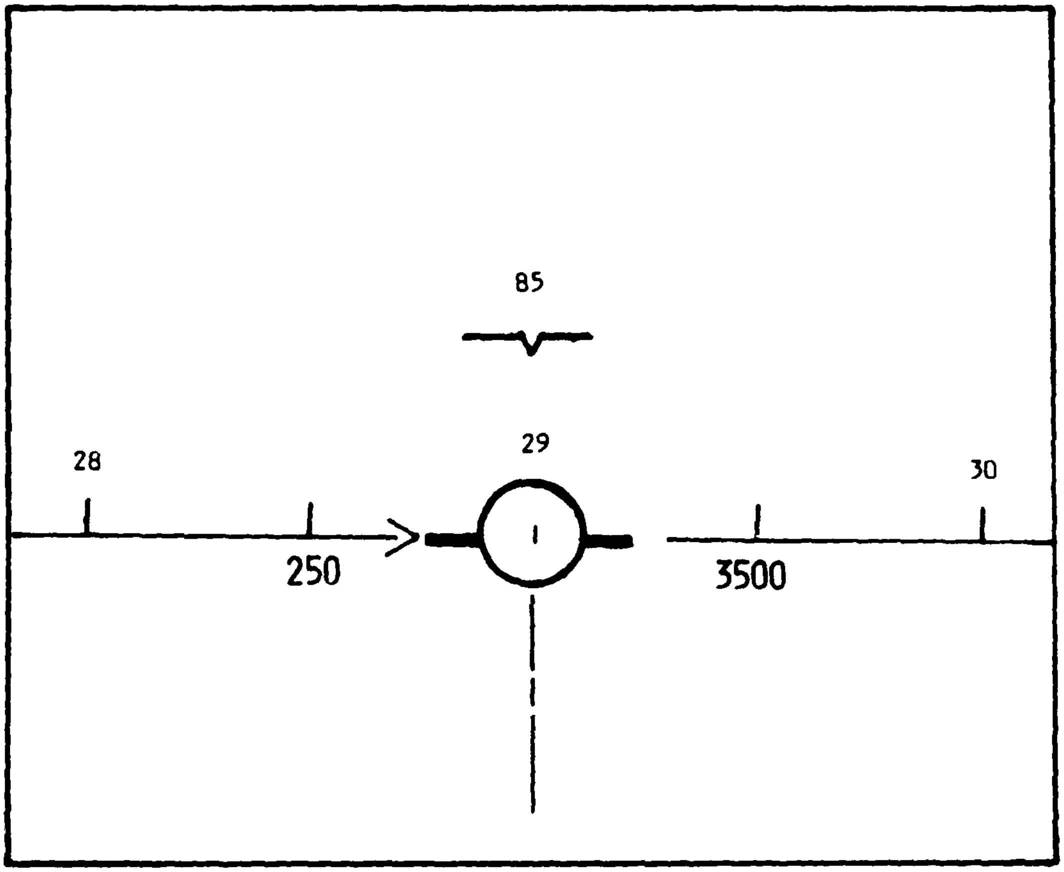

FIGURE 12. REPRESENTATIVE HUD EN ROUTE SYMBOLOGY AT FLIGHT LEVEL 350

engineer's station were extremely awkward. In the terminal area maneuvering, its use by the right seat safety pilot represented a very unwelcome additional workload. Nearly all of the required inputs to the system should have been effected by the left seat pilot himself, thereby eliminating the inevitable confusions arising from the failures of inter-pilot communications. The data input sequence itself (callout-set-execute) was unacceptably complex and error-prone.

Several changes were made to the PMCP. Rather than reading in new values of runway length and width for every runway used, it was felt that most runways would be approximately 10,000 feet in length and 150 feet wide so these values were made constant. The "runway" button functions for length and width were respectively changed to Magnetic Variation and Selected Heading.

Programmable Graphics Generator-Computer - The static integrity of the symbology, both geometric and alphanumeric, was adequate. However, the capacity of the PGG for computation of symbol position algorithms was severely limited. This obviously contributed to many of the problems encountered. Required programming methods were very tedious and severely constrained and provisions for system and algorithm verifications were minimal. Consequently, an excessive amount of flight time was expended discovering and correcting software errors.

Symbology position update rates were extremely slow. Due to the limited computer capacity, various elements of the display were positioned at approximately 12, 6, 3 or 1.5 Hz. Normally, a 2 to 30 Hz rate would be specified for all symbology. The consequences of these slow rates will be discussed in the Software section.

No condsideration could be given to the provision of gyro drift compensation algorithms for use in the airmass mode. Also, computation of a drift angle during localizer or VOR tracking, in the absence of an INS derived value, was not implemented. Unfortunately, without drift angle, the airmass display mode was essentially incomplete and could not be given a complete evaluation.

During operations in which the aircraft's flaps were initially extended large power transients would develop. These transients were caused by the air conditioning pack fans automatically coming "on" when flaps are initially selected to the 2 degrees position. This would cause certain pilot selected variable values (e.g., magnetic variation, runway elevation, etc.) to be lost or erased as inputs to the PGG computational circuitry; however, these values would appear to remain intact when read from the display of the PMCP. A recommended fix was to ensure that pilot selected variable values be read back from resident memory in the PGG and not from the interactive controller.

Sensors - Data Interface - The INS derived data (attitude, heading, drift angle and vertical acceleration) appeared to be of the anticipated accuracy and precision. However, drift angle was updated at a much slower rate (0.7 Hz) than was called for in the display concept and was implemented in the simulation. No provision was made for interpolation to higher rates. The consequences of this situation are discussed in the Software section.

The outputs of the air data computer appeared to be of the desired accuracy and precision as were the outputs of the navigation receivers. The directional and attitude gyro outputs were reliable but demonstrated the anticipated "drifts" when compared to the INS data.

"Software" Elements of the System - Discussion in this section will address findings related to software items, specifically symbology, control laws and programming problems.

A small amplitude vertical jitter or stepping existed in all but the several fixed elements of the display. This was the source of continued minor irritation to the test team. The motions were probably the result of attitude signal noise coupled with the positioning resolution of the computer. During active maneuvering, and especially when turbulence was inducing angular motions on the aircraft, the slow and varied symbol positioning update rates resulted in anomalous jerky relative motions between related elements.

The very slow data rate associated with the INS drift-angle and the smoothing lag it necessitated, resulted in the presentation of a flightpath symbol that was not inertially stabilized at the normal yawing oscillation frequencies of the airplane. The consequences were considered serious since the display concept called for controlling an inertially referenced element (the flightpath symbol) to inertially referenced guidance elements. Thus, in turbulence, the yawing motions of the aircraft produced a low-frequency lateral "noise" on the flightpath symbol that significantly increased the pilot's lateral control workload. The effects of this anomaly were minimized in smooth air.

The gain on the ILS localizer indication was reduced to one-third of that determined to be desirable in simulation (12:1 down to 4:1). This reduction was implemented in an effort to minimize what appeared to be a noisy localizer signal. However, since the convergence time constant for localizer tracking is proportional to this gain, this resulted in a very slow convergence to the localizer when the normal tracking mode was used. In turbulence, the combination of low error gain, slow update rate on drift angle and the slow computer resulted in an unacceptable level of localizer tracking precision.

Another error was found in the positioning of the localizer error indication prior to localizer intercept (localizer error greater than 2.5°). Instead of being positioned to give the pilot a more intuitive feel for position with respect to the localizer comparable to existing HSI presentations, the localizer error line would stay directly underneath the course line until the aircraft came within 2.5° of the localizer at which time it would jump to the correct position. This problem was discovered early in the flight validation work, but attempts to program it correctly failed. In combination with the previous problems this resulted in an awkward presentation that was usable in the intercept maneuver, but could be counted on to confuse the pilot in his early experience. It did not provide explicit guidance during the early stages of the intercept turn.

Some other programming errors were recognized and if possible, corrected. The pitch references, which were intended to be laterally positioned as a function of selected heading (one-degree increment marks and the negative pitch references), did not always reflect the intended logic. Also, the vertical position of the altitude reference symbol included an error that was proportional to the product of bank angle and drift angle. This had the potential of presenting a confusing contradiction between altitude error as displayed by the symbol and that noted by reading the digital altitude during turns in strong crosswinds.

Several symbology changes were made as a result of the experience using the HUD en route from the FAA Technical Center to BCAC. The DME range readout was increased to 99.9 nmi and above 15,000 feet the speed error symbol, γ reference line and pitch ladder symbol are blanked out.

Conclusions - At the completion of the installation and validation phases, it was felt that the performance of the various hardware elements of the HUD system was adequate to continue into the flight evaluation phase. As far as symbology and control laws, in the INS mode, the display demonstrates the basic flightpath and information integration concepts developed in simulation. However, the inadequate computational speed, software errors, and awkward input procedures result in a system that is far short of that usable in-service.

In the airmass mode, without the computation of drift angle during localizer or VOR tracking, the display was essentially incomplete and could not be given an extended evaluation. All problems and shortcomings in the display were explained to the subject pilots prior to their first flight.

FLIGHT EXPERIENCE/EVALUATION PHASE

In this phase, a unique opportunity was available to the FAA/NASA HUD research team. In the past, the most effective means of passing information along to FAA regional and headquarters personnel has been through the use of the flight simulation capability at NASA-Ames Research Center. Now, by adding the capability of the Head-Up Display Research System in the B-727, the opportunity to further examine the Head-Up Display concept in a joint simulation/flight test exercise was available. The specific objectives of this simulation/flight experiment were as follows:

1. To provide the FAA regional pilots with "hands-on" experience with an operational head-up display.

2. To obtain a direct assessment of the transfer of HUD training from simulation to flight.

3. To examine the use of HUD as a monitor for an auto-land system in low visibility conditions.

4. To evaluate performance with this HUD under more difficult operational scenarios.

5. To qualitatively assess the degree of validity of the simulation results to date.

SUBJECT PILOTS.

Seven FAA pilots and two NASA pilots participated as full subjects. The seven FAA pilots came from both flight test and operations groups in Seattle, Washingtion, Los Angeles, California, and Washington, D. C. The two NASA test pilots were from the Ames Research Center and both had previous experience with advanced displays.

SIMULATOR SESSIONS AND FLIGHT SESSIONS.

The original plan called for each participant to have three flight sessions and at least three simulator sessions. Under ideal conditions, the following sequence of events took place. Upon arrival, all participants were formally briefed on simulator operating procedures and given a refresher in the characteristics of the HUD, using video tapes of the display. The subjects had been sent literature on the HUD prior to arriving at Ames. In fact, seven of the nine subjects had previous experience with the display. The primary objective of the first simulator session was training in the use of the display. The session consisted of air work, landings, precision and nonprecision approaches, terminal area maneuvering, and go-arounds with extensive pilot/instructor interaction during the session.

Following the training period in the simulator, the subject was briefed on his first flight with emphasis on how to operate the HUD, what capabilities are available with the system, what the crew procedures would be, and what would be done on the flight. The actual flight test scenarios will be discussed later in the report.

The second simulator session followed and concentrated on the use of the HUD as a monitor for the auto-land system in low visibility operations. It was recognized that the subjects would not use the HUD during this flight program as a monitor or in low visibility situations; however, it was hoped that this exercise would provide some help to the region pilots in future auto-land certifications. A briefing for the second flight would follow the simulator session.

The last simulator session consisted of a series of more difficult operational scenarios designed to explore the fringe areas of the operating envelope to assess whether HUD can significantly improve the pilot's ability to detect and handle situations that push the pilot/aircraft system to its limits. All subjects were also encouraged to use the simulator time to further explore any conditions that they had encountered in the flight sessions. The third flight session was then designed to allow the subjects to look at conditions that were not identified in the test plan or to repeat flight experiments they had previously done.

FLIGHT PROCEDURES

This section provides a detailed description of the procedures used in conducting the data collection flight tests.

Preflight Briefing - Prior to each data collection flight, a formal briefing for all participants was held by the Test Conductor. All in-flight aspects of the operation were thoroughly briefed by the project pilot (safety pilot). The following items were discussed:

Refresher on HUD symbology.
HUD operating procedures.
Boeing 727 operating and emergency procedures.
Crew coordination and responsibilities.
Route of flight. (figure G-1 of appendix G)
Flight scenarios.

Operating Procedures - The subject pilot occupied the left seat. His first task was to adjust the seat for proper eye level and eye-to-PDU distance. The FAA

Technical Center Safety Pilot occupied the copilot's seat on all flights, and was the pilot-in-command responsible for all safety aspects and execution of the project flight. He was able to observe the HUD display on the small monitor located in front of him beneath the glare shield and he could confirm whether the HUD presentation was correct and also evaluate the subject's performance.

Inasmuch as all subjects were jet transport qualified, a total crew concept was exercised, with the subject pilot flying the airplane and handling the power levers. The copilot's duties were carried out by the safety pilot in addition to operating the HUD PMCP and taking care of the communications and air traffic control (ATC) clearances. The flight engineer assisted as needed when the workload became excessively high for the safety pilot. Since all cockpit communications were recorded on the audio channel of the video recorder, the subjects were encouraged to make comments during and after each data run for post-flight scrutiny.

Before taxi, all standard aircraft checklists and the HUD checklist were accomplished. (A complete list of all HUD checklists is found in appendix F.) During the taxi for takeoff, the pertinent takeoff parameters were selected and entered into the PMCP by the safety pilot. These parameters included critical engine failure/rotation speeds (V_1/V_R), speed error reference, takeoff/go-around (TO/GA) flight mode, altitude reference, magnetic variation, runway heading, gamma slew, and gamma reference. The takeoff was closely monitored by the safety pilot including all standard callouts, but was accomplished by the subject pilot who derived his information solely from the HUD. As the aircraft accelerated along the runway, the speed error "worm" decreased. When it indicated "0" error, the aircraft was rotated to takeoff attitude. After takeoff, either the IMC or Visual Meteorological Conditionds (VMC) mode was selected on the HUD. The standard departure (figures G-1 through G-4 of appendix G) was adhered to utilizing the HUD which was being updated with new headings, airspeeds, altitudes, and VOR references by the safety pilot. When out of the immediate airport traffic area, the subject pilot was free to maneuver VFR en route to the test areas. In general, the subject had about 15 minutes of en route time.

Flight Scenarios - The desired test sequence called for each subject to fly his first session during daylight with the HUD in the inertial mode. The second flight session was then flown during dusk and night conditions with the HUD in the airmass mode. The third flight session was optional and could be flown in whatever conditions the subject desired within existing aircraft and/or operational limitations.

During each of the first two sessions, the first three approaches for each subject pilot were visual HUD approaches using no guidance from the ground. Generally, the last of these was a circling approach. During the daytime operations, the visual approaches were accomplished at the Crows Landing Navy Auxiliary Landing Facility located about 46 nautical miles (nmi) east of Moffett Field. However, no dusk or night operations were allowed at Crows Landing. Consequently, the night visual approaches were conducted at Stockton Airport located about 50 nmi northeast of Moffett Field.

At the completion of the visual approach segment, each subject then flew four instrument approaches. These four approaches consisted of two with full ILS guidance, one with localizer only, and one hooded approach to a decision height of 200 feet or lower with full ILS guidance. These were all completed at Stockton Airport. A summary of the various flight profiles is found in appendix G.

A typical flight session would be conducted in the following sequence. The subject pilot who made the takeoff would stay in the left seat and fly the airplane over to Crows Landing (figure G-5 of appendix G). Upon arriving in the vicinity of Crows Landing, the crew would complete the aircraft and HUD descent/approach checklist and the required HUD configuration and all landing variable inputs would be entered through the PMCP by the safety pilot. Straight-in approaches were conducted to runway 30 (figure G-6 of appendix G). With the winds predominantly from the northwest, approaches to runway 30 were essentially into the wind. The initial segment of the circling approaches was conducted to runway 30 and upon overflying the airport at a MDA of 800 feet m.s.l., circling left turns to runway 35 were performed. The HUD was utilized for altitude and airspeed control while circling. The effect of crosswind on the approaches to Runway 35 could be readily observed on the HUD.

Commensurate with each subject pilot's experience and performance, the approaches were terminated either with a go-around or a touch and go. During go-around and touch and go maneuvers, the TO/GA mode was selected and the HUD was utilized for climbout with the safety pilot updating airspeed, heading, and altitude information. After the first subject pilot completed his VFR approaches, an "in the air" change of subjects was accomplished, with the second subject conducting whatever airwork he felt he needed and then completing his set of visual approaches.

Upon completion of the work at Crows Landing, the second subject pilot would then navigate the aircraft to Stockton Airport (figure G-7 of appendix G), utilizing VOR information displayed on the HUD. A rectangular traffic pattern at Stockton was entered with the safety pilot "radar vectoring" the subject around the pattern (figure G-8 of appendix G). The ILS approaches were conducted to runway 29R at a pattern altitude of 2,000 feet. Each run was terminated with a go-around or touch and go, and again the HUD was utilized for the entire pattern including climbout. At least one run was conducted under simulated instrument (hooded) conditions to a decision height of 200 feet or lower depending on the subject pilot's performance and the discretion of the safety pilot. (A simple dark rectangular shield was inserted between the HUD and the windshield, blocking the outside view, but allowing full use of the HUD. This shield was then retracted by the safety pilot at decision height.) When the second subject pilot completed his ILS approaches, the first subject pilot would return to the seat and finish his runs.

Upon completion of the flight test card, the aircraft would depart the Stockton area VFR with a climb to 9,000 feet m.s.l. and then transition to Bay approach control for radar vectoring into the NAS Moffett traffic pattern (figure G-2 of appendix G). The vectoring information was input to the HUD with the subject pilot utilizing the HUD for all maneuvering. The vectors resulted in very long and high final approaches to Moffett NAS Runways 32L and R or 14L and R, which gave the subject pilots ample opportunity to again evaluate the VFR capability of the HUD system.

Back-Up Airport - A back-up airport available to the flight test team was Travis Air Force Base in Fairfield, California. Travis was selected because it has a well known history of strong wind shears and a CAT II ILS approach on runway 21L (figure G-9 of appendix G).

Post-Flight Debriefing - After each flight, the subject pilots were debriefed by the test conductor and the test team. All comments were recorded on a tape recorder. Inasmuch as the video tape from the airplane was available for immediate playback, the subjects and other participants had the opportunity to review the data runs on the TV set during the debriefing.

PILOT QUESTIONNAIRES.

In addition to the onboard data collection system previously described, extensive use was made of the pilots' commentary. All subjects were asked to fill out three comprehensive questionnaires. The first was a general questionnaire covering the use of the display in each of the flight segments to which the subject pilots were exposed. The second questionnaire specifically addressed the comparison between the airmass mode and inertial mode. The final questionnaire was concerned with the physical characteristics of the HUD. The three questionnaires are found in appendix H.

RESULTS

GENERAL COMMENTS.

The test aircraft and crew arrived at NASA-Ames on June 13, 1981. Testing began as scheduled on June 15. Due to a combination of hardware and software problems, the simulator was inoperable for most of the first week. Since the airplane and subject pilots were only available for a limited time, a decision was made to concentrate on the flight test part of the program and to use the simulator when available for training or to further examine any particular problem areas uncovered during the flight tests. It was decided to examine the use of HUD as a monitor for auto-land in low-visibility conditions and the more extreme operational scenarios informally as time permitted. Also, any observations on the validity of simulation results or the transfer of training from simulator to flight would strictly be qualitative in nature.

In retrospect, the decisions made were good ones in that the simulator reliability remained somewhat low while the airplane performed flawlessly. A total of 12 test flights were accomplished for a total of 36 flight hours. Table 2 contains a summary of each subjects exposure; i.e., number of flights, total number of approaches broken down by test condition and the number of touchdowns. This table does not include the landings at Moffett Field after each test flight.

With the exception of a minor aircraft electrical problem prior to the first flight, the test aircraft operated the entire time without a failure of any kind. This was even more remarkable considering that the ambient temperatures during the first week were over 100° F most of the time.

OVERALL ANALYSIS OF HUD CONCEPT.

In analyzing the results of this program, several important points stand out and must be discussed before continuing. First, the comments are broken down into three categories; i.e., (1) Broad comments that refer to the concept of HUD in general, (2) more specific comments that refer to a type of HUD concept within the broad classification of head-up display (e.g., flightpath HUD, flight director HUD, visual approach monitor, etc.); and (3) comments that refer to the particular HUD used in this program and its unique characteristics. Second, the test team was

TABLE 2. SUMMARY OF SUBJECT PILOTS' FLIGHTS AND APPROACHES

			APPROACHES WITH INS HUD				APPROACHES WITH AIRMASS HUD			
SUBJECT	NO. OF FLIGHTS	TOTAL APPROACHES	VISUAL	ILS	LOC ONLY	HOODED	VISUAL	ILS	LOC ONLY	HOODED
1	3	18/13*	5/1	3/3	1/1	2/1	4/4	3/3	0	0
2	2	13/11	4/3	2/2	1/1	2/2	2/1	2/2	0	0
3	3	17/13	4/2	5/4	0	4/4	3/2	1/1	0	0
4	3	19/15	4/2	2/2	2/2	2/2	5/3	2/2	1/1	1/1
5	2	11/8	3/2	1/1	0	0	3/1	2/2	2/2	0
6	3	19/44	6/2	4/3	1/1	4/4	2/2	2/2	0	0
7	3	19/44	3/3	2/2	0	0	3/1	2/2	1/1	1/1
8	2	12/10	3/3	2/1	1/1	2/2	2/1	2/2	0	0
9	2	13/12	4/3	4/4	1/1	0	2/2	2/2	0	0
	TOTALS	134/106	36/21	25/22	7/7	16/15	26/17	18/18	4/4	2/2

*18/13 18 Approaches, 13 Touchdowns

aware of certain problems with the HUD due to a variety of reasons prior to the start of the evaluation exercise. In discussing the results, it is important to differentiate between comments relating to known deficiencies and those relating to new or unexpected findings. Also, all comments that either support or refute previous simulation findings will be highlighted.

For convenience, we will discuss the results in the same categories as the pilot questionnaires are set up. All of the pilot comments from the questionnaires are summarized in appendix I.

Terminal Area Maneuvering - In general, the comments regarding the adequacy of roll, pitch, and heading information were mixed. Certainly, having the display information superimposed with the outside scene and with the same scaling provided more precise information to the pilot. However, several subjects commented that they were less aware of pitch attitude either because of the location of the pitch symbol or because there was a tendency to ignore pitch while concentrating on the flightpath symbol. In particular, one subject felt that HUD was better in that flightpath is what must be controlled and not pitch attitude, given that there will not be a time when controlling flightpath could result in an aircraft pitch attitude that cannot be sustained without pilot awareness.

Several subjects made some negative comments about the roll information in the display. The primary concern seemed to be the lack of a specific reference which would allow the pilot to know his precise bank angle. Similar comments had been made in past simulations, particularly regarding terminal area maneuvering where larger bank angles are generated than during final approach segments. In lieu of a scale or specific reference, some additional bank angle information can be designed into the shape of the flightpath symbol, e.g., by replacing the short horizontal wings of the flightpath symbol with "gull" wings that slope 25 to 30 degrees.

Opinions regarding situation awareness with respect to heading were quite varied. Several subjects commented that there was a tendency toward a high workload when trying to hold a precise heading due to the sensitivity, or when making large heading changes and rolling out on the desired heading which required a certain amount of pilot interpretation. In the INS mode, the ability to fly course instead of heading was acceptable. There was some concern that the split between the pitch symbol and the heading scale made for a high workload.

With regard to speed and altitude control, the subject pilots unanimously rated the HUD as the same or better (very much better in most cases). The digital readouts were easy to read. Having airspeed, altitude, fast/slow, gamma, and potential gamma all together greatly reduced the scan requirements. Most subjects felt that the combination of airspeed error worm and potential gamma symbol allowed precise speed control although two subjects felt that the workload was also increased. There was a tendency to chase speed in turbulence and fly to much smaller tolerances than normal since the precision was available. Of course, workload items like this could decrease considerably as experience is gained. Similar comments were made about altitude control. There was a tendency to go after 10 to 20 feet changes which was not the case with conventional altimeters. The single action task of placing the flightpath symbol on the horizon to hold altitude was greatly appreciated.

The altitude reference lines were felt to be a good aid when approaching the desired altitude but, once altitude was captured, they proved to be somewhat confusing. The scaling was too great for small excursions and the lines themselves tended to get lost in the clutter of the horizon and pitch scale lines. It was suggested that the lines themselves be made more conspicuous since the concept was a good reminder system once the pilot was aware of the symbols. The opposite comment was made regarding the airspeed error worm symbol. It was too large for small errors and tended to glow and mask other symbols. One approach for alleviating this undesirable characteristic was to eliminate two of the four vertical lines which constituted the speed error worm symbol and to decrease its length by a factor of two by changing its scale factor from 4 knots per degree to 8 knots per degree. Also, a case was made for removing the symbol altogether until the aircraft is close to final approach and then possibly tying the error to the flap speed schedule. This latter approach would bring the symbol into the display in the flight modes where speed error is most important and remove it as a potential distraction in other modes.

In response to the question concerning situation awareness of position and path relative to the localizer, all the subjects felt the HUD was the same or worse than head-down instruments. This negative response was fully expected since, as previously described, the course line and localizer capture logic were not implemented correctly. The subjects could not perceive accurate pictures of their position relative to the ILS as they could with the head-down HSI. It was difficult to comprehend whether the aircraft was left or right of the runway, especially with the flightpath symbol seemingly on the wrong side of the course line to make an intercept. This created a very high mental workload.

For the localizer capture itself, the same negative comments were made. When the localizer symbol came off its parked position, it was such an abrupt movement that it was easy to miss. Consequently, if the pilot did not turn immediately, it very often resulted in an overshoot. There were no lead-in cues comparable to what the pilots were accustomed to with conventional head-down presentations.

Since the comments and experience regarding position and flightpath relative to the ILS and the localizer capture maneuver were strongly influenced by the incorrect implementation of the HUD symbology control laws, it is not possible to directly compare results with previous simulation experience. However, it is safe to say that, in the previous work, one area of potential concern with regard to HUD design relates to the integration of horizontal and vertical situation information. In the phase III study, although the flightpath HUD contained enough information to support the localizer intercept maneuver, some of the subject pilots had difficulty determining their horizontal situation in this phase of operation. The exact cause of their difficulty was not determined. However, all these subjects had accumulated vast experience with panel displays that use separate instruments for horizontal situation information (HSI) and vertical situation information (ADI). Now, with the advent of electronic displays such as HUD, it is possible to integrate horizontal- and vertical-situation information into one common display format. The effective design of such displays is not an easy task, however, and results from the experience, to date, indicate that additional work is needed.

<u>ILS Approach</u> - We will limit discussion, in this and subsequent sections, to those comments that are either new or represent a change of opinion from previous commentary. For example, since the comments regarding speed control are the same in the approach phase as in the terminal area maneuvering phase, we will not repeat them.

In commenting on the effectiveness of the HUD in terms of ease and precision of control of maintaining position on the ILS, the majority of subjects felt it was better with the HUD, particularly in the INS mode. The ability to fly a more precise localizer and glideslope was apparent but seemed to require an increased workload to accomplish it. The reduced scan pattern needed did offset the workload increase for some subjects. Three of the subjects felt that the display was not as good as the head-down presentation in providing status information on displacement from the ILS. Overall, the comments regarding ILS tracking and situation awareness are consistent with previous experience. During the initial exposure to flying the flightpath symbol and having a display with 1:1 scaling instead of typical 5:1 scaling of an ADI, the workload is high. Once the pilot becomes comfortable with the dynamics of the display, he then must develop a new set of references so that he knows what errors and displacements are acceptable and what he must do to keep within these tolerances. Often, when exposed to the concept of following the "ghost airplane" to track the ILS, there is a tendency to lose the habit of checking raw data for localizer and glide-slope error. The task of flying the flightpath symbol to the "dot" is director-like in nature, even though there is no command information in the display. A definite learning period is needed for the pilot to develop his technique for interpreting all the information available to him. Some subjects suggested a quantitative measure of ILS deviation such as a "CAT II box," relative to the flightpath symbol, be added to the display.

The subject pilots were mixed in their response on the effectiveness of the display in providing rate of descent information. About half of the subjects felt that vertical speed is provided via the flightpath symbol and this should be adequate once some limits are established. Others felt a strong need to know actual rate-of-descent in feet per minute. The primary motivation for this seemed to be the desire to have a better feel for vertical speed during nonprecision approaches. In fact, four subjects responded that vertical speed was one of the additional items they would like to see in the display in this flight segment.

As previously described, during the ILS approaches, a runway symbol appeared in the display at 1,000 feet altitude and then disappeared at the selected decision height (usually 200 feet). The theory behind removing the runway symbol at decision height is that the real runway should be visible at decision height and, by removing the artificial runway, you reduce clutter in the critical landing segment. In at least one other display concept, the opposite approach is taken and the artificial symbol does not appear until close to flare height. Eight of the nine subjects felt that the presentation in this exercise was better than head-down in presenting status information on location of the runway. Some suggestions for improving the symbol design were made. In this presentation, the sides of the artificial runway extended to the horizon line (figure D-11 of appendix D). This was a departure from the simulation format necessitated by the reduced computation capacity. As the aircraft approached localizer centerline and decision height, the combination of runway lines, course line, and localizer error line tended to all come together and mask each other. A suggestion was made to shorten the runway symbol by cutting off the side lines and leaving only the threshold and maybe half of the runway side lines in the display, which was closer to the format originally intended. One subject felt that once the real runway was visible, the artificial runway should be removed regardless of decision height in an attempt to reduce clutter and superfluous information. These comments supported previous findings and added credence to the contention that having the runway symbol in the HUD could help the pilot find the real runway sooner when going from IFR to VFR conditions.

Nonprecision Approaches - The questions in this section address the effectiveness of the head-up display in the management of flightpath from the final approach fix (FAF) to the minimum descent altitude (MDA), specifically regarding provisions for rate-of-descent control, altitude awareness, MDA capture and hold, and localizer guidance. Rather than comment on each question, the responses to all of them we will summarize to give a picture of the total maneuver. The basic piloting task was to push the flightpath symbol over until it reached the -5° pitch lines and hold it there (at typical approach speeds this is approximately -1,000 fpm) until the altitude reference lines appear in the display. As these reference lines pass the flightpath symbol, the pilot follows the lines until the flightpath symbol and reference lines are all on the horizon. At this point, the aircraft is in level flight at the MDA. The consensus of opinion among the subject pilots was that the HUD was better than the head-down presentation for accomplishing this maneuver. The use of the flightpath symbol and the -5° lines seemed easy and effective for maintaining a constant rate-of-descent. The MDA reference lines were helpful for recognizing and capturing MDA. However, one interesting situation occurred during one of these runs on a night flight. The subject pilot found himself concentrating very intently on seeing the altitude reference lines since he had experienced difficulties in seeing these lines on previous runs. The altitude reference line was to have been set at the MDA of 450 feet but, inadvertently, this was not done. Consequently, the subject pilot flew through the MDA and descended to 300 feet before he realized what had happened. It was the safety pilot who alerted him that he was getting low. The subject pilot commented that he had found himself locking on to the display too much and not integrating the outside scene into his view as he should.

Visual Approaches - The subjects could also fly the nonprecision visual approaches in another manner. After establishing a lateral line-up using either the localizer or the real runway, the pilot continues toward the runway maintaining level flight. As the -3° fixed depression dots pass the threshold of the runway, the subject then pushes the flightpath symbol over and maintains it on the desired touchdown point. If the aircraft is on an optimum -3° flightpath, the fixed depression dots and the flightpath symbol will overlay the touchdown zone. If the aircraft is high or low, the pilot then adjusts his flightpath accordingly to keep the fixed depression dots over the touchdown zone. For the INS mode, the subject pilots found this to be quite easy and acceptable. Several suggestions were made to make the fixed depression line longer so as to increase its usefulness in larger crosswinds and in the circling approach and to make the dots more conspicuous. The subjects had major problems with this technique using the airmass mode, but this will be covered later in the report.

Of course, this second technique does require that the pilot be able to see the runway. The farther away the aircraft is, the more difficult it is to see the runway and the smaller it appears. At some point, the symbology tends to cover the entire runway environment and it becomes impossible to differentiate the threshold and the touchdown zone. However, the technique can still be used and the pilot can fly very consistent and precise paths and, as the runway becomes larger and more visible, finer adjustments to the flightpath can be made. The ability to fly precise flightpaths without guidance from the ground has been indentified in the previous work as an advantage that is somewhat unique to the conformal flight path displays. The results of this experience add support to these findings.

Visual Segment of ILS Approach - The subject pilots were asked to comment on the contributions or problems offered by the HUD in regard to the evaluation of visibility conditions during IMC-VMC transition. Unfortunately, all the test flights were conducted under clear weather conditions so the only opportunity to assess this transition would have been in the simulator. Only a few of the subjects had the opportunity to see the lower visibility situation in the simulator. The subjects that responded to this question, either based on simulation or possibly previous experience, felt that the HUD aided in evaluating the visibility conditions during transition from IMC to VMC. Any future flight test effort with the HUD should examine the low visibility transition area.

Two of the questions in this section ask whether the display aided the pilot in coping with wind shears and crosswinds. Atmospheric conditions for all the test flights were generally mild. Winds ranged from calm to a maximum of 25 knots and were usually within ±30° of the runway heading. Turbulence levels were light for the majority of flights with a limited exposure at moderate levels. The most severe conditions encountered were the ambient temperature levels which exceeded 100° F on most of the day flights. Very little comment was made regarding the ability to maintain flightpath and speed in shears while using the HUD. The subject pilots were not really exposed to any significant shear conditions although, by monitoring the INS wind readouts, some small lateral wind shears were observed by the experimeters and easily handled by the pilots. The exposure to crosswind conditions was somewhat greater. Most runs had some crosswind component while the circling approaches usually had a significant crosswind component. The subject pilots rated the HUD in the INS mode as the same or better than head down instruments in coping with crosswinds. For the airmass mode, the HUD was rated worse.

When asked if the HUD deprived them of information that is normally available either in the panel or in the visual scene, the subjects responded no, except for vertical speed or engine information. In response to the question of whether they utilized the "declutter" option, six of the pilots responded that they had not used it. The others used it at night or between 50 and 100 feet altitude. There was some support for making it automatic because the pilot may forget to declutter.

Some very interesting answers were given to the question regarding the extent to which the pilots assessed the "outside" view of the runway relative to the displayed information. Two pilots said that they first tended to fixate on the HUD but, after several approaches, they were able to look through the display at the outside scene quite easily. The consensus of opinion was that the outside scene information was used at least 75 percent of the time. There was a strong reliance on the outside scene for lineup horizontally and more dependence on the HUD for vertical flightpath information and speed. This pattern of being able to use the outside scene more extensively, as experience with the HUD is gainrd, is consistent with past simulation experience. While only a qualitative assessment can be made, it seems that the pilots used the outside scene more in these flight tests than other pilots had used it during previous simulations. This is not surprising, since the simulator's visual scene is not as compelling and rich in cues as the real-world scene. Also, some of the simulation work is done under IFR conditions where the pilot only has the display information. A great deal of experience is gained using the HUD alone and when a less than optimum visual scene appears, there is little reluctance to rely on the HUD information alone.

The issue of dividing time between the HUD and outside scene has previously been referred to as attentional or perceptual switching. Past experience with the HUD concept indicates that there is a definite attentional cost associated with using a HUD, but not unlike using a flight director or some new instrument. While using a HUD reduces the physical movement of the head and eyes required to scan the instrument panel and the outside world, it is still necessary for the pilot to mentally scan; i.e., to alternate his attention between the HUD symboly and the outside visual cues. It has been felt that this scanning requires a deliberate action on the part of the pilot. Several examples were noted during the phase III simulation exercise that indicated the mere presence of a stimulus in the visual field does not guarantee that it will be perceived. One conclusion reached during this study was that the design of the HUD itself may alter this attentional switching; i.e., it may be possible to design a HUD in such a way that scanning behavior is enhanced. The HUD used in this flight program is a good example. For the precision ILS approach case, this HUD is self-contained in that it contains enough information to fly the entire approach, flare, and landing maneuver without references to outside visual cues. Therefore, the display does not require attentional scanning of the external scene. By eliminating the flare guidance symbol, it would be possible to change this situation such that, at some point prior to and during the flare, the pilot would be forced to attend to the visual environment. In the flight program, the pilots always had the "flare line" guidance so that a test of this premise was not conducted. However, when questioned about their use of the flare guidance, the pilots gave some very interesting and varied responses. The utilization of the flare line ranged from very little to 100 percent use. Some of the pilots only used it to initiate the flare maneuver while others used it to the greatest extent possible. Only one subject felt that there was a dilution of normal cues when using the flare line and his comment was that it caused tunnel vision. Several pilots felt that the symbol itself tended to get lost in the clutter as it passed the flightpath symbol and suggested that it could be made more prominent.

Go-Around - Eight of the nine subject pilots responded that they used the HUD in the go-around maneuver. Having flightpath and potential flightpath information made it easy to fly a constant speed climbout. This provides the opportunity to get maximum performance from the aircraft which is not possible using head-down displays. There was also an advantage to having the precise attitude information and having the pilot head-up and looking outside. Pilots definitely did not like having the flightpath symbol change shape during the maneuver; i.e., from the approach "bulls eye" flightpath symbol of figure D-3 of appendix D, to the TO/GA "bow tie" flightpath symbol of figure D-4.

Three of the subjects felt that greater familiarity with the use of the HUD in the go-around would have been helpful. In the past, other subject pilots have had varying degrees of difficulty getting accustomed to using a flightpath HUD in the go-around maneuver. To accomplish a go-around using conventional panel instruments, the pilot would typically pull the nose of the aircraft up to some predetermined pitch attitude (e.g., 15°), establish a positive rate of climb, and then attempt to establish some new target speed and take whatever climb gradient (flightpath) results. With the HUD, the pilot now has a direct readout of flightpath. He can simply pull the flightpath symbol up past the horizon which is a positive rate of climb, and once go-around power is set, pull the flightpath symbol up to the potential flightpath symbol and he has established his maximum constant speed climb gradient. He can then adjust to a particular target speed as needed. The confusion that usually exists is often simply an unfamiliarity with the actual flightpath angles to expect out of the airplane. This is generally cleared up by additional training.

AIRMASS VERSUS INERTIAL HUD.

The pilots evaluated the HUD in two different operational modes; i.e., the inertial (INS) mode and the airmass (AM) mode. As previously described, the AM mode had not been fully implemented and could only be partially evaluated. Otherwise, the primary difference in the display was in the quality and amount of information being used. In the INS mode, the aircraft's heading, attitudes, groundspeed, ground track, and accelerations are provided by an inertial navigation system and are representative of the high quality data that would be expected in the new generation transport aircraft. In the AM mode, the HUD inputs are from the aircraft's gyros and a three-axis body mounted accelerometer package and are more representative of what might be found in existing fleet aircraft without INS. A complete description of the two modes is found in appendix D.

The test plan called for each subject to fly the first flight using the HUD in INS mode and the second flight using the airmass mode. The third flight was the optional and either mode could be used. However, if the subject pilots felt they had seen enough of the airmass mode prior to completing the second flight, they could switch back to the INS mode. This was allowed because, under certain atmospheric conditions, the two modes would appear almost identical when flying precision approaches. Consequently, subjects were given the option to expand their exposure on one mode at the penalty of reduced exposure on the other. The final totals for the entire program showed 84 approaches with the INS mode and 50 with the airmass mode.

When asked which mode they preferred, the subject pilots unanimously said the INS mode. Their comments to the various questions were given both in terms of the desirable features of the INS mode and the undesirable features of the AM mode. Since the remarks about the INS mode have been covered in the previous discussion, we will limit our comments here to the AM mode. One of the more undesirable features of the AM mode was the separation between the flightpath symbol and the ILS information. The larger the crosswind condition, the larger the drift correction needed and, consequently, the separation between the flightpath symbol and ILS information in the display becomes greater. This in turn makes it more difficult for the pilot to control flightpath and maintain glide slope and localizer. However, under calm conditions with no drift correction, the display appears to be almost identical to the INS mode. The pilots felt very strongly that this separation of information was very unacceptable and much worse than the INS mode. Interestingly, while the subjects generally felt that the presentation and interpretation of required drift corrections was much worse for the AM mode, they felt that the accuracy of the information was about the same for both modes.

In order to quantify the subjects performance relative to localizer and glide slope tracking for the INS mode and AM mode, selected approaches were subjected to a limited data reduction and analysis. These included 25 INS approaches and 20 AM approaches. To preclude a possible biasing of the results due to subject pilots intentionally maneuvering from localizer and glide slope centerline, only approaches in which the pilots were established with inbound guidance before 1,500 feet AGL and continued to a low approach or touchwdown were selected. However, data for analysis purposes were restricted to altitudes between 1,500 feet AGL and 100 feet AGL. The approaches were subdivided into a final approach segment and a decision segment. The final approach segment started at 3 nmi before touchdown (MBTD) and continued to 300 feet AGL ($\approx$ 1 MBTD); and the decision segment started at the end of the final approach segment and continued to 100 feet AGL ($\approx$ 1,000 feet before runway threshold).

For each approach segment, recorded localizer and glide slope deviations were catalogued into three separate groupings of 0° to 0.2°, 0.2° to 4° and > 0.4°. A percentage of occurrence was then computed, based upon the accumulated totals for each grouping and the total for each approach segment. A compilation of these data are contained in table 3. Also, plots of representative INS and AM approaches for each of the subject pilots are contained in appendix J.

With regards to localizer tracking, these data substantiate that tighter tracking; i.e., better performance was demonstrated by the subjects using the HUD in the INS mode. This disparity in INS and AM localizer tracking performance is readily apparent from the localizer deviation approach plots of appendix J and can most likely be attributed to the subjects inabilities to readily interpret the AM HUD display to effect the correct drift correction. Another factor possibly contributing to this disparity in localizer deviations, was the misalignment of the real-world runway centerline and the localizer guidance as displayed on the HUD. This is discussed elsewhere in the report.

For glide-slope tracking performance, the data again substantiates that better tracking was demonstrated in the INS mode, although the difference in performance was not as prevalent as for localizer tracking. One factor which may have contributed to better INS mode glide-slope tracking is that during the INS mode approaches the subject was not required to devote a large portion of his scan time to determining required drift corrections; thus he has more time to devote to glideslope tracking. During the decision segment of the approaches, larger glideslope deviations were recorded than during the final approach segment. Again, this is as expected, since during this approach segment the pilot typically transitions from the predominate use of HUD symbology guidance to external visual references and initiates final alignment with the outside runway environment in preparation for landing.

In the AM mode, the vertical response of the flightpath symbol while maneuvering seemed to be more acceptable. Whatever differences were there seemed to be small. A more serious problem was the effect of gyro precession errors on the display. These were demonstrated by having the pilot fly a visual approach using the HUD but with the glideslope and localizer information removed from the display. The pilot could fly the approach maintaining the fixed depression symbol on the touchdown zone and then monitor the raw glide-slope data on the head down ADI and see a consistent two-dot high error.

FINAL QUESTIONNAIRE.

The primary purpose of the final questionnaire was to get the subject pilots views on any findings that were unique to the flight portion of the program and specifically to the fact that they were using actual flight hardware in the real-world environment. Most of the subjects had never been exposed to an actual head-up display as differentiated from a simulated one. The first question asked if they had any problems with the physical location of the display unit, four of the subjects responded that they had some degree of trouble. The most common problem

TABLE 3. PERCENT OF OCCURRENCE OF LOCALIZER AND GLIDE SLOPE DEVIATIONS FOR INS AND AM APPROACHES

	INS			AM		
APPROACH SEGMENTS	LOCALIZER DEVIATION (DEGREES)			LOCALIZER DEVIATION (DEGREES)		
	0 - .2 (%)	.2 - .4 (%)	>.4 (%)	0 - .2 (%)	.2 -.4 (%)	>.4 (%)
Final Approach Segment (3 MBTD* to 300' AGL)	89	11	0	60	26	14
Decision Segment (300' AGL to 100' AGL)	92	8	0	77	16	7
	GLIDESLOPE DEVIATION (DEGREES)			GLIDESLOPE DEVIATION (DEGREES)		
	0 - .2 (%)	.2 - .4 (%)	>.4 (%)	0 - .2 (%)	.2 -.4 (%)	>.4 (%)
Final Approach Segment	96	3	1	85	13	2
Decision Segment	73	24	3	60	21	19

*MBTD-Miles Before Touchdown

was that, if the pilot sat in the correct eye position, then he was too close to the controls. The solution seemed to be to sit in a comfortable position and then lean forward as necessary to use the entire display. One subject commented that during a missed approach he was depressed into the seat and tended to lose sight of about half of the display. (This issue of proper location for the PDU is a critical one for the designer.) For any head-up display, it is very important that the pilot's eyes be in the proper eye reference position in order for him to see the entire display field. The amount of tolerance for movement away from this eye reference position varies as a function of the type of optical system being used.

Two of the pilots encountered a very severe problem related to the physical installation of the PDU. When the acrylic block is unstowed, there are both lateral and longitudinal flight detents that must be checked by physically pushing the acrylic block to the left and then toward the pilot. Failure to observe this precaution could result in erroneous pitch attitude relative to the outside visual scene. In the process of changing pilots in-flight, the PDU acrylic block was inadvertently bumped out of its longitudinal detent and when the next subject got in the seat, the detent check was not performed. The new pilot proceeded to make several visual approaches before the problem was discovered. To the pilot flying, the HUD symbology looks fine but it is not referenced correctly to the outside scene. However, the amount of displacement was not so large as to be immediately apparent, and it was not until an approach or two had been made and the subject pilot commented that he seemed to have some difficulty getting down to a 3° path, that the problem manifested itself. One solution is to have a microswitch located in the detent so that the symbology could not be displayed unless the PDU is in the correct position.

A second question asked for comments on the visual qualities of the display such as brightness, distortion, clarity, jitter, etc. All of the subjects commented that the jitter, caused by the inadequate size and speed of the host computer or possibly by D/A and A/D converters in the Interface Unit, was obvious but, in general, everyone was able to disregard it enough to adequately use and evaluate the display. The brightness control seemed to have enough range to accommodate all conditions encountered. There was some distortion and saturation at full scale but it was not necessary to use the full range. Almost every subject got to view a wide range of contrast levels ranging from full daylight through dusk and into full darkness and many saw it on approaches directly into the sun and found it to be very good. The brightness had to be turned down for the dusk and night operations as the bright symbology would mask the runway environment which was not well lighted. There did not appear to be any distortion or clarity problems with the symbology except at the full brightness control setting. Several suggestions were made regarding changes to symbol size and intensity in an effort to make the display more readable.

Only one pilot experienced any eye discomfort. He felt this was due primarily to symbol jitter and excessive symbol clutter and overlay during IMC approaches. The artificial runway, flightpath symbol and ILS glide-slope circle could overlay each other and reduce the conspicuity of any separate symbol.

One issue sometimes raised with regard to head-up displays is that of symbology fixation. This refers to the tendency for a pilot to become engrossed with certain elements of the display to the exclusion of other sources of information either within the display or elsewhere. The phenomenon of fixation is not unique to head-up displays. Pilots can become engrossed with following the command information on present head-down flight directors and miss callouts or can concentrate very intently on the touchdown zone of the runway and not use other sources of information in the outside scene. However, with head-up displays, the issue is somewhat unique in that the pilot is dealing with two superimposed sets of information. We specifically asked the subjects if they noticed any tendency to fixate on any elements of the display to the exclusion of other elements or the real-world scene. Almost all of the subjects responded that, to varying degrees, they had experienced fixation. The greatest tendency was to fixate on the flightpath symbol and ILS information. The most serious example occurred on the night localizer-only approach when one subject was concentrating on not missing the MDA reference line and flew 100 to 200 feet below MDA before realizing that the reference had not been set.

There was some agreement that this tendency toward fixation was reduced as experience was gained with the HUD. In fact, some subjects said that after only a few approaches, they were able to overcome it. All of the subjects felt that they were able to take their attention away from the display and return to it comfortably. These comments lend support to a conclusion based on previous work that the task of scanning a HUD and then being able to direct your attention away from it is a skilled behavior that can be acquired through appropriate training and experience.

Interest has been expressed in the past on whether there is any tendency for head-up display symbology to mask or obscure necessary outside cues such as approach lights, runway lights, markings, or other aircraft either airborne or on the ground. The subject pilots were asked about this and some good comments were made. Several subjects felt that the brightness of the display tended to obscure the touchdown zone and runway environment during night landings. This could be remedied by turning the brightness down or by using the declutter option. There was concern voiced about the ability to see other aircraft traffic through the HUD during approach at night. Several pilots felt they picked up traffic by looking around the HUD, not through it, and one felt that the display, particularly the edges, would obscure other aircraft which are quite small angularly. One argument that is often used in support of the use of HUD is that it will improve the pilots chances of seeing other traffic since he is already head-up and his eyes are accommodated to infinity. Since none of these flights were made using head-down instruments, it is not possible to say whether the pilots ability to see other traffic during this exercise was improved or degraded, but it is worth examining further in any future flight tests.

ADDITIONAL OBSERVATIONS.

During the course of this program, some interesting observations were made about items not covered by the test plan. We will discuss some of these findings in this section.

Takeoff - All of the subject pilots got the opportunity to make at least one takeoff from Moffett Field using the HUD. While considerably less time has been spent looking at this HUD in the takeoff mode than in approach and landing, the basic procedure used was very simple and easy to understand. The speed reference was set for the computed V_R speed which resulted in the flightpath symbol showing a huge speed error as the aircraft was taxiied into position. As the pilot applied takeoff power and accelerated, the potential gamma symbol would rise well above the flightpath symbol which stays on the horizon until liftoff. As the aircraft accelerates down the runway, the speed error will start to decrease. When the speed error disappears altogether, the aircraft is at rotation speed and the pilot rotates the aircraft, causing the pitch attitude symbol to rise in the display.

CONCLUSIONS

At the end of phase IV of the HUD Concept Evaluation Program, approximately 100 hours of flight experience using the HUD had been accumulated. In addition, many hundreds of hours of flight simulation time had been logged in phase II using this HUD as well as others. Many individuals from all parts of the aviation community participated. At this point, it seems appropriate to draw some general conclusions from the total experience to date.

One very important objective of the flight test program was to assess the degree of validity of the simulation results to date. Clearly, if enough findings from the flight experience agreed with the simulation experience, then more confidence could be placed on the entire simulation program results. The general consensus among the subject pilots in the flight experience phase was that the simulation fidelity was excellent and that the transition from the simulated aircraft and HUD into the real aircraft using an actual display was very comfortable and easily accomplished. This confidence in the realism of the simulation, and the extent to which it was representative of what was seen in-flight, added credence to the many comments concerning flight test results that were in direct agreement with simulation findings. The general conclusion must be that in the areas of interest that were examined in both simulation and the flight program, the results of the flight experience closely followed the simulation results.

Another broad objective of the flight program was to examine the use of the HUD in areas that could not be addressed in simulation. These included night operations, approaches directly into the sun, circling approaches, en route operations, steep visual approaches, and of course, when weather conditions permitted, operations in low visibility, rain, and other more severe atmospheric environments. With the exception of low visibility operations, some degree of exposure to all the other areas was achieved with many excellent comments recorded and no major problem areas identified. Overall, the level of confidence in the results of flight tests conducted in areas not previously addressed in simulation is very high.

A major area of interest to the project team upon initiating the installation, validation, and evaluation phase of the project was the level of accuracy of the aircraft sensors and their effect on the HUD operation. This particular conformal flightpath-based head-up display format was developed and evaluated under the assumption that in an aircraft it would, under the most favorable circumstances, be supplied precise attitude, velocity, and acceleration data from modern sensors, including INS. If the sensors were less accurate, as might be found on presently operating domestic transport aircraft, then the performance of this display concept might be effected significantly. The flight test aircraft for this program offered the unique opportunity to examine HUD performance using high quality data from modern sensors as well as lower quality information from the aircraft's existing sensors (which could be considered representative of the type of information available in a large percentage of the commercial aircraft fleet presently in service). The results of this exercise overwhelmingly support the HUD designer's premise that high quality data is essential for optimum performance of this type of display concept. While the use of lower quality data could not be completely eliminated based on results of this experience, it was apparent that either the HUD design would have to be altered or some extensive software modifications would be needed to accommodate sensor inadequacies. Given the choice, high quality sensors are of paramount importance if the full potential of a conformal flightpath display such as this one is to be recognized and utilized.

Shortly after liftoff, the flightpath symbol will also rise to some new flightpath. The pilot can either use a pitch attitude as his target, take whatever flightpath he gets and then adjust his speed accordingly or he can use flightpath and potential flightpath directly and establish whatever climb angle he needs.

For some of the subjects, their first experience with a HUD as well as a 727 aircraft was this takeoff. Overall, results of using the HUD during takeoff were quite positive. No major problems were encountered and some good suggestions were made. The most common problem was a lack of training in what flightpath to look for. Several pilots had some trouble locating the pitch symbol during the ground roll and then, as rotation was accomplished, it became hard to see because it was at the top of the display. Several favorable comments were expressed about using the speed and speed error to indicate V_R to the pilot.

Circling Approach - Seven of the subjects had the opportunity to fly a circling approach. No particular problems were exposed and all the runs seemed to be satisfactory. The pilots were able to nicely maintain altitude during the turns and felt that the fixed depression line helped them determine when to start down to a three-degree path, although the fixed depression line itself may have been more helpful if it extended to the edges of the display. This was the first chance in the joint program to look at circling approaches as the simulator's visual system was inadequate to address them earlier.

Steep Approaches - Two of the pilots had unexpected opportunities to fly a steep nonprecision approach using the HUD. The first subject was cleared for a visual approach to Moffett from an altitude of 7,500, feet 240 knots, clean configuration from a position quite close to the field. He proceeded to set up a -6° flightpath and using the flightpath, potential flightpath and the real runway, went through all the configuration changes and made a very easy approach and landing at Moffett. The second pilot inadvertently turned in too close to the runway during a visual approach to Stockton and was well above a nominal 3° path. Again, using flightpath and potential flightpath information, he set up about a -7.5° flightpath until he reached a nominal -3° path and then continued along the -3° path to a landing, all accomplished quite nicely. Having the precise control of flightpath and the energy management information that the potential flightpath provides makes these types of approaches considerably easier for a pilot.

Misalignment of Localizer Guidance Symbol and Runway Centerline - During the ILS approaches to RWY 29R at Stockton, it was observed that there was a misalignment of approximately 0.15° between the HUD displayed localizer and synthetic runway centerline, and the real world runway centerline. Although not readily apparent during the initial segment of the approach, this misalignment was noticeable during the mid- and final-approach segments in which the real world runway centerline was discernible. This misalignment was manifested by a fly left indication from the localizer guidance symbol and the synthetic runway, when in fact, the aircraft would be aligned with the runway centerline. Conceivably, this small misalignment error could have contributed to the percentage of localizer deviations of table 3; however, its effect is not readily determinable, since it cannot be determined at what point in the approach the pilot reverted from HUD localizer guidance to external visual runway centerline references. Most of the localizer deviation plots of appendix J exhibit this misalignment anomaly. A subsequent check with the Los Angeles Flight Inspection Field Office (FIFO) revealed that there were no abnormal or out of tolerance localizer guidance signals reported during the period of the flight experience/evaluation.

When the overall FAA/NASA- Head-UP Display Program was initially established, the primary task for the project team was to explore the use of HUD in approach and landing operations. As experience with various display concepts was gained, it became obvious that the more advanced display concepts such as the one described in this report could be used in other flight regimes. Within the limits of the simulation capabilities, areas such as go-around, takeoff, and limited terminal area maneuvering were explored. However, once the research HUD was installed in the test aircraft, all limitations were removed and the use of the HUD was examined throughout the entire flight envelope. While only 100 hours of flight experience with HUD has been accumulated, the conclusion reached by the project team is that the HUD can be comfortably and very effectively used as the primary flight instrument throughout the aircraft's flight envelope. The high degree of precision that the HUD provides and the ease with which it can be used could provide the commercial transport pilot with a very versatile and more efficient means of operating his aircraft and utilizing both his own and the aircraft's capabilities within the existing aviation system.

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APPENDIX A
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APPENDIX B

THE PILOT'S MODE CONTROL PANEL

The Pilot's Mode Control Panel (PMCP) (figure B-1 of appendix B) provides the pilot with the capability of selecting flight modes, GAMA slew commands, declutter operations, guidance modes, self-test, and to relinquish control to the test conductors/interactive controller position. Also, it provides the ability to input operational variables such as runway elevation (MSL), magnetic variation, referenced indicated airspeed, etc., and to select desired courses, headings, etc. Its detailed operations, including other functions, are described below:

1. HUD PWR - HUD power switch controls power to the Interactive Controller. The light in this switch should be illuminated whenever power is applied. Switches which require input should also be illuminated and include ALT REF, γ REF, IAS, GS, ELEV, MAG VAR, HDG SEL, and CRS/HDG. The ENTR and ALT REF switches should be flashing indicating these switches are active. The digital readout should be displaying an initial ALT REF of zero.

2. PUSH TO TEST - Push to test switch operates a light test which should illuminate all switches and display 8's in the LED digital readout. NOTE: Use of this switch after initialization may disrupt computer operation requiring reinitialization.

3. ENTR - Enter switch inputs to the computer the selected variable displayed in the digital readout. This switch should be flashing which indicates a variable input function is selected and the computer will accept the displayed value.

4. SYMB FAIL - Symbol fail switch should flash when an unreliable sensor is detected (if sensors are redundant, both systems must fail before this switch is activated). The symbology on the heads-up display will then flash until the symbol is pushed. Pushing the symbol fail switch will steady the light and symbology. Test configurations must then be selected to operate with the unreliable sensor(s) in accordance with procedures outlined in the Operations Manual. If the failed sensor again becomes reliable, the symbol fail light will extinguish.

5. ALT REF - ALT REF switch is used to select a reference altitude (level-off, MDA, DH) in feet above ground level (AGL). When ALT REF is selected, the lights in the ENTR and ALT REF switches will flash until an entry is made or another function is selected. If no value has previously been input and another function is selected before making an entry, the ALT REF switch light will remain illuminated to signify an input is still required. After initial power up, ALT REF will be automatically selected for input. The initialized reference value will be set to zero which should be displayed as 0 (leading zeroes are suppressed) in the digital readout. This setting of zero inactivates the altitude reference symbol. In order to activate the altitude reference symbol, a value other than zero must be input. The toggle switches can be used to select an altitude reference from 0 to 50,000 feet AGL; however, the value will not be entered to the computer or head-up display symbology until the ENTR switch is pushed. For test, set in 200 feet using the toggle switches and enter. The ALT REF light should extinguish while the γ REF light flashes indicating it as the next variable to be input. Confirm the altitude reference entry by selecting ALT REF. The digital readout should read 200 feet.

6. γ REF - γ REF switch is used to select the flightpath reference for input. Basic operation of this switch is as described for ALT REF. An initialized value

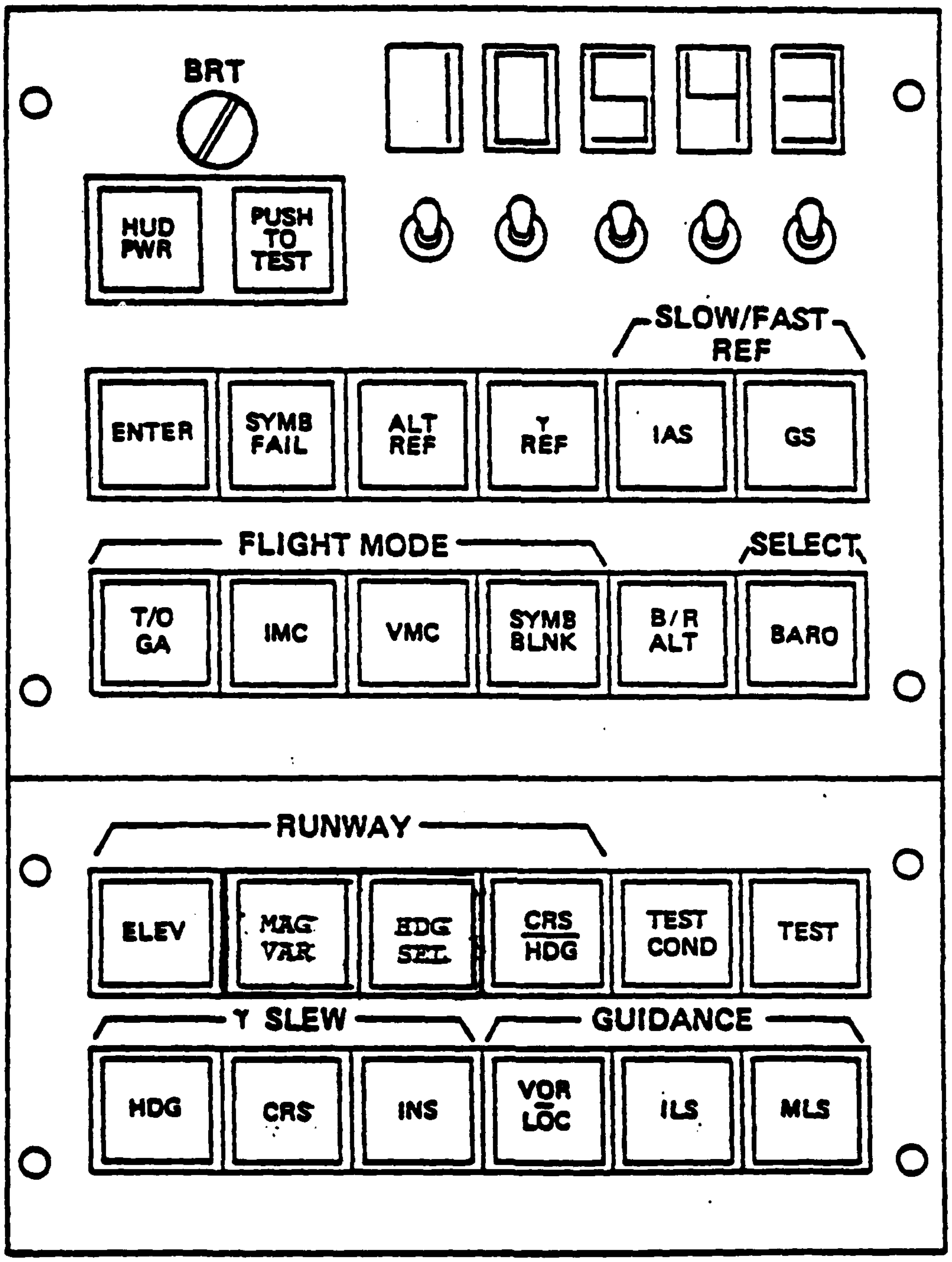


FIGURE B-1. PILOTS MODE CONTROL PANEL

of -3° is preset and should be displayed. The display shows degrees in one-hundredth of degree increments which allows a range of settings from -9.99 to 30.00 degrees. The decimal point is not displayed; therefore, -3° will be displayed as I 0300 (the minus (-) or negative symbol will be displayed as a (I) symbol only in the furthest left display). The toggle switches can be used to change the flightpath reference, which will be entered when the ENTR switch is pushed. After entry, the REF light should extinguish and the IAS light should flash (if IAS value has not previously been entered).

7. IAS - IAS switch is used to select the indicated airspeed reference for input in the same manner as described for ALT REF. The reference value displays knots and can be set in one knot increments from 0 to 500 knots. An initial value of 127 knots is preset and should be displayed when first selected. After entry, the IAS light should extinguish and the GS light should flash.

8. GS - Groundspeed switch is used to select the groundspeed reference for input. Entry of a preplanned groundspeed reference is accomplished as described above for ALT REF. This reference value is displayed in knots and can be set in one knot increments from 0 to 500 knots. The initial reference setting is zero which should be displayed in the digital readout. This setting eliminates groundspeed from the speed error algorithm so that speed error is simply a comparison of indicated airspeed to the selected IAS reference. With any other value selected for GS reference, and assuming INS groundspeed available, the speed error compares airspeed error and groundspeed error. The speed error bar displays the minimum of the two errors which, as long as the speed error is kept on or above the flightpath wing, will prevent the aircraft from slowing below either groundspeed or airspeed references. After GS entry, the GS light should extinguish and B/R ALT light should flash. CAUTION: The airspeed/groundspeed algorithm may cause large airspeed excursions necessitating large trim changes during wind shear or other high wind conditions.

9. FLIGHT MODE - Flight mode switches, TO/GA, IMC, VMC, and SYMB BLNK are used to select the symbology to be displayed. TO/GA, IMC, and VMC flight mode switches, respectively, select the required symbology for takeoff - go around, IMC, and VMC flight conditions; therefore, only one of these switches can be selected at any one time. The mode selected should be indicated by the switch which is lit. The symbol blank switch (SYMB BLNK) is used for declutter and blanking of the symbology in each of the flight modes. The symbol schedule shows the symbols which should be displayed for each mode. Each mode, when selected, should display the symbols per the respective column "a" listing of the symbol schedule. These symbols should be confirmed by observing the SYMBOL SELECT switches on the test conductor's panel. A light should be illuminated in each switch corresponding to a symbol. Declutter the symbology by pressing the SYMB BLNK switch one time. The illuminated SYMBOL SELECT switches should correspond to the respective declutter mode as listed in column "b" of the symbol schedule. The second press of the SYMB BLNK switch should remove all symbology from the head-up display. The symbol blank switch is cyclic in that the third operation will return the displayed symbology to that listed in column "a" of the symbol schedule.

10. B/R ALT - Baro/Radio ALT switch is used to select an altitude at which the altitude readout will change from barometric altitude (MSL) to radio altitude (AGL). The input value will represent an altitude in feet AGL and can be set in

one foot increments from 0 to 2,000 feet. The initialized value will be set to 200 feet. After entry of the changeover altitude, the B/R ALT light should extinguish and the ELEV light should flash.

11. BARO - The baro switch is used to select barometric altitude to be displayed throughout the entire approach to touchdown. After power up, this switch is "unselected" (light should be off) and the digital readout will automatically change from barometric altitude (designated by the letter "B" displayed above the readout) to radio altitude (designated by the letter "R" displayed below the readout). This changeover should occur at 200 feet radio altitude.

12. ELEV - Elevation switch is used to select runway elevation for input. Upon initialization, no value will be displayed which will inactivate the runway symbol until another value in feet MSL is set in the digital readout. Entry of elevation should extinguish the ELEV light and the LNTH light should flash. A standard runway length of 10,000 feet and width of 150 feet are internally programmed.

13. MAG VAR - The magnetic variation switch selects the variation correction to be applied to INS true heading to enable course, heading, runway positioning, etc., to be entered in magnetic referenced values. This function is only meaningful when using INS sensor inputs.

14. HDG - This switch enables a selected heading to be input to the PGG. This selected heading controls the positioning of the pitch ladder and gamma reference symbols when outside 2.5° of localizer centerline.

15. CRS/HDG - Course/heading switch selects final approach course for input. Zero (0) will be displayed on initialization which represents magnetic north (000). The digital readout will display values in whole degrees from 0 to 359 after entry. Assuming all other inputs have been completed, lights in all switches requiring input and ENTR light should be extinguished and symbology corresponding to the selected mode should be displayed.

16. TEST COND - The test conductor switch is used for the test program only and would not be part of a production unit. This switch gives the pilot control over which mode control panel is active. After initial power-up, the TEST COND switch is off indicating that the pilot has control of the mode control panel while the test conductor's mode control panel is an inactive repeater of the pilot's panel. The panel may relinquish control to the test conductor by selecting TEST COND. When the TEST COND switch is selected indicated by illumination of the switch, the test conductor's mode control panel becomes operational and the pilot's mode control panel becomes an inactive repeater except for HUD PWR, TEST, and TEST COND switches which remain operational at the pilot's panel. NOTE: The TEST COND switch is operational only at the pilot's mode control panel.

17. TEST - The test switch is used to check that the symbol generator is concurrent with the drive electronics unit. Operation of this test is accomplished as follows: Set the VIDEO toggle switch of the HUD drive electronics to the TEST position. This switch position will cause a cross-hair pattern to be displayed. Then press the TEST switch on the mode control panel. This actuation will initiate the test. A second cross-hair pattern should then rotate 360 degrees about the center point and again coincide with the stationary pattern. Upon test completion, which takes about 30 seconds, the TEST switch must again be pressed to remove the

second cross-hair pattern. Returning the VIDEO toggle switch to the NORM position will allow the selected symbology to be displayed. NOTE: The TEST switch is operational only at the pilot's mode control panel. If the TEST switch is pressed with the VIDEO switch still in NORM, the symbology will blank and the test will operate without the stationary reference cross-hair displayed. If the arithmetic processing unit (APU) has faulted, the word RESET will be displayed on the HUD after the TEST switch has been pressed. Reset of the system can be accomplished by pressing the Memory Address CLR/LOAD switch on the symbol generator. CAUTION: This test must be accomplished prior to any approach and/or takeoff maneuver in which the HUD is to be used. If the test cannot be run successfully, do not use the HUD.

18. γ SLEW - γ SLEW switches, HDG, CRS, and INS, are used to select the mode of lateral positioning of the flightpath symbol. Only one of these switches can be selected at any one time. HDG should slew the lateral position of the flightpath symbol to the aircraft heading. This slewing will position the flightpath symbol in line with the A/C REF symbol (center of display). CRS should slew the lateral position of the flightpath to the selected course reference limited to ±8 degrees of the center of the display. INS should slew the lateral position of the flightpath to overlay real-world flightpath, limited again to ±8 degrees of the center of the display. If the test configuration is in an INS mode, γ slew will use INS unless HDG or CRS is manually selected. If the test configuration is in an airmass mode, γ slew will switch to HDG. CRS may be manually selected; however, INS cannot be selected while in an airmass test configuration mode.

19. GUIDANCE - Guidance switches, VOR, ILS, and MLS, are used to select the navigational signals needed to drive the localizer and glidepath symbols. During the flight evaluation, the MLS function was not operational.

APPENDIX C

THE HUD DECLUTTER SYMBOL SCHEDULE

The symbol schedule (figure C-1) shows the symbols which are displayed for each mode. Each mode, when selected, displays the symbols per the respective column "a" listing of the symbol schedule. These symbols can be confirmed by observing the SYMBOL SELECT switches on the test conductor's panel. A light will be illuminated in each switch corresponding to a symbol. Declutter operations are effected by pressing the switch one time. The illuminated SYMBOL SELECT switches will correspond to the respective declutter mode as listed in column "b" of the symbol schedule. The second press of the switch will remove (blank) all symbology from the head-up display. The symbol blank switch is cyclic in that the third operation will return the displayed symbology to that listed in column "a" of the symbol schedule.

Selectable flight modes		T/O-GA				IMC				VMC			Notes
Column SW Declutter	Modes	a	b	Blank		a	b	Blank		a	b	Blank	
Name													
A/C REF		1	1	0		1	0	0		1	0	0	
γ REF (A)		0	0	0		0	0	0		0	0	0	17
HORIZON		1	1	0		1	1	0		1	1	0	
PITCH		1	1	0		1	0	0		1	0	0	
MAG HDG		1	1	0		1	1	0		1	1	0	
AIR SPD		1	1	0		1	1	0		1	1	0	3
ALT		1	1	0		1	1	0		1	1	0	3
SEL CRS		0	0	0		1	0	0		1	0	0	12
HDG SCL		1	0	0		1	0	0		1	0	0	
ALT REF		1	1	0		1	1	0		1	0	0	
AIM PT		0	0	0		0	0	0		0	0	0	4, 7, 9
γ ANGLE		1	1	0		0	0	0		1	1	0	15
γ REF (B)		1	0	0		1	1	0		1	1	0	18
FLT PATH		0	0	0		1	1	0		0	0	0	16
FP ACCL		1	1	0		1	1	0		1	1	0	
SPD ERR		1	1	0		1	1	0		1	1	0	3
RUNWAY		0	0	0		1	0	0		0	0	0	1, 2, 7, 8, 9, 11
α LIMIT		1	1	0		1	1	0		1	1	0	13
FLARE		0	0	0		1	1	0		1	1	0	
R/W ℄		0	0	0		1	0	0		0	0	0	1, 2, 5, 7, 8, 9, 11
T/O REF		1	1	0		0	0	0		0	0	0	
LOC		0	0	0		1	0	0		0	0	0	1
GP LIN		0	0	0		1	1	0		0	0	0	1, 2, 10
GP CIRC		0	0	0		1	1	0		0	0	0	1, 2
CRS LIN		0	0	0		1	0	0		0	0	0	1, 2, 6, 9
MARKERS		0	0	0		1	0	0		0	0	0	1, 14
DME		1	1	0		1	0	0		1	0	0	1

1 = On
0 = Off

Notes:

1. Symbol will be off when test configuration is in AIR REF or INS REF (no guidance available)
2. Symbol will be off when guidance is in VOR/LOC
3. Symbol will be off when both FLT PATH and γ ANGLE are off
4. Symbol will be off when both R/W ℄ and CRS LIN are off
5. Symbol will be off when RUNWAY is off
6. Symbol will be off when RUNWAY is on
7. Symbol will be off when $h_p > 1{,}000$ ft
8. Symbol will be off when $h_p < 70$ ft
9. Symbol will be off when $h_p < h_{ref}$
10. Symbol will be off when $h_w < 50$ ft
11. Symbol will be off when beyond Cat II limits (i.e., $|e_{loc}| > 0.39$ deg or $|e_{gs}| > 0.35$ deg)
12. Symbol will be off when $\Delta\psi < 15$ deg
13. Symbol will be off when $\alpha > 10$ deg
14. Symbol will be off except at marker passage
15. Symbol will default to FLT PATH
16. Symbol will default to γ ANGLE
17. Symbol will default to γ REF (B)
18. Symbol will default to γ REF (A)

FIGURE C-1. SYMBOL SCHEDULE

APPENDIX D

THE HEAD-UP DISPLAY FORMAT

1. INTRODUCTION.

This section describes the head-up display symbology used in this program and discusses some of the operational procedures for using it. Differences between the symbology used in the flight tests and that used in the simulation are described. For a complete description of the control laws employed, see reference 1 of appendix A.

1.1 SCOPE OF DISPLAYED INFORMATION.

The display elements and format presented herein are intended to provide complete flight guidance information for terminal area maneuvering, landing, go-around, takeoff, and limited en route operations for civil transport aircraft. Both INS and AIRMASS configurations are defined. The INS display format assumes the availability of inertially derived ground-track heading information, whereas the AIRMASS format, while utilizing the same display elements, does not include this assumption. The variations which describe the AIRMASS configuration are defined at the end of each section.

1.2 GENERAL DESCRIPTION.

The displayed information is presented in a total field-of-view measuring 30 degrees in width and 26 degrees in height. About the airplane's longitudinal reference axis, this field is distributed symmetrically in the horizontal plane, and depressed 6 degrees in the vertical plane. The display is designed to be "conformal," that is, elements of the display that reflect changes in aircraft attitudes move at the same angular scaling as do the outside visual references. Some display elements are intended to overlay earth references. An indication of the direction of the aircraft's instantaneous flightpath, referenced to the longitudinal axis of the aircraft (and thus to pitch and directional references, as well as terrain references in VMC) is a principle element of the display.

1.3 SENSOR REQUIREMENTS.

The basic display is designed to be operated in aircraft equipped with either a full INS system or VG, DG, and 3-axis body mounted accelerometers (referred to as "airmass equipped"). Note that the INS accelerometer outputs would probably be far superior for the INS case if the data are accessible. The flightpath angle computation requires a complementary filter for turbulence which uses vertical acceleration as an input. For the INS case, this data would come from the INS, and for AIRMASS it would come from the body mounted accelerometer. Due to problems with the body mounted vertical accelerometer, the vertical acceleration output of the INS had to be used in the AIRMASS mode. When using the body mounted accelerometers, because of differences in location relative to the aircraft c.g., the gains and time constants of the flightpath computation must be adjusted accordingly, in order to yield proper dynamic response.

Signals from an air-data computer are required including airspeed, barometric altitude and altitude rate. Navigational guidance requires optional selection of ILS glideslope and localizer (or VOR), marker beacons, radio altitude and DME. other parameters which may be manually input to the computer by the pilot or test conductor are:

Runway (localizer) magnetic heading reference
Selected Heading
Magnetic Variation
Field Elevation
Reference airspeed ("target")
Reference groundspeed ("minimum")
Reference altitude (assigned, MDA, or DH)
Gamma Reference (ILS or desired glideslope angle)
Baro/Radio altitude select (changeover from baro to radio)

1.4 AIRMASS.

In the absence of an INS system, navigational data representing the earth-referenced track of the aircraft is unavailable, thus the flightpath heading, relative to airplane heading, cannot be explicitly displayed. Flightpath, therefore, must be slewed (e.g., " γ SLEW") either to aircraft heading or the selected course when using airmass flightpath algorithms. Also, a measure of ground speed, necessary for the determination of climb or descent angle (vertical flightpath) is unavailable. Thus, an approximation, based upon indicated airspeed, must be accepted.

2. DISPLAY DETAILS.

2.1 AIRCRAFT FIXED ELEMENTS.

Those display elements which are fixed in position angularly on the display are:

2.1.1 Aircraft Reference - The apex of this symbol shown in figure D-1 defines the origin of the position referencing system. For the 727 airplane, this origin is situated 6 degrees above the center of the display frame, and is centered laterally in the frame.

2.1.2 DME -The readout is shown in figure D-1. The display reads in miles and tenths, when less than one hundred miles. Maximum mileage displayed is 99.9 miles.

2.1.3 Magnetic Heading - Readout of magnetic heading to nearest whole degree is displayed as shown in figure D-1.

2.1.4 Marker Beacons - At marker beacon passage, the appropriate "O" (for outer marker) or "M" (for middle marker) will appear flashing in the position shown in figure D-1 for the duration of the signal. (The signal should flash at 4 Hz but, during the flight tests, it flashed at a considerably lower frequency and was found to be unacceptable by the pilots.)

2.1.5 Angle-of-Attack Limit - Positioned as shown in figure D-1, this symbol appears flashing at 4 Hz when the angle-of-attack is greater than 10 degrees.

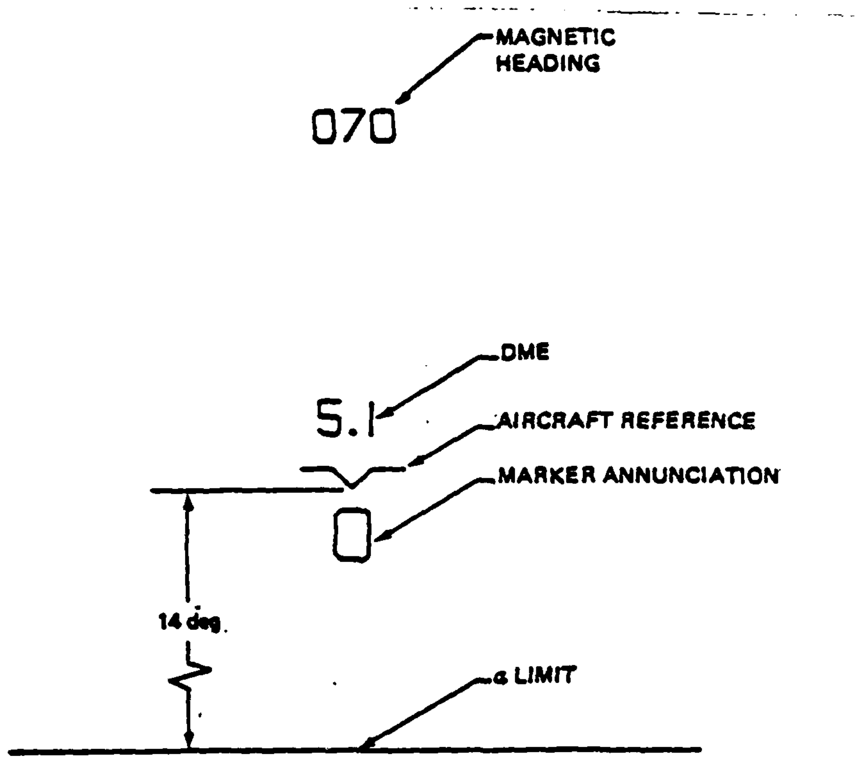


FIGURE D-1

(This function was not examined during the flight evaluation but has been found to be acceptable in simulation.)

2.2 ATTITUDE REFERENCES.

The presentation of roll, pitch, and heading is shown in figure D-2 for the case where runway heading (localizer heading) is displayed. Shown is a roll attitude of 6 degrees, a pitch attitude of 6 degrees above the horizon, and a heading of 087 degrees, three degrees left of the runway magnetic heading reference of 090 degrees. The selected runway heading is represented by the center of the break in the horizon line. The 5- and 10-degree interval markers (above the horizon) are centered laterally about the aircraft reference symbol, but the one-degree markers above the horizon and the attitude references below the horizon, are centered laterally about either the runway heading indication or localizer. The minus 5-degree pitch is indicated by two short dashes. A pilot selectable gamma reference is seen as a series of 8 dashes. If the difference between aircraft and runway heading is greater than 15 degrees, a digital reading of runway heading will appear below the horizon and to the left or right side of the display corresponding to the direction to the runway heading.

2.3 FLIGHTPATH SYMBOL ARRAY.

As indicated in paragraph 2.1, the display features a symbol that defines the direction of the instantaneous flightpath of the airplane relative to the longitudinal axis of the airplane and to inertial (earth) references. This symbol is intended for use as the primary controlled element of the display; thus the pilot is able to directly control his vertical and lateral flightpath rather than

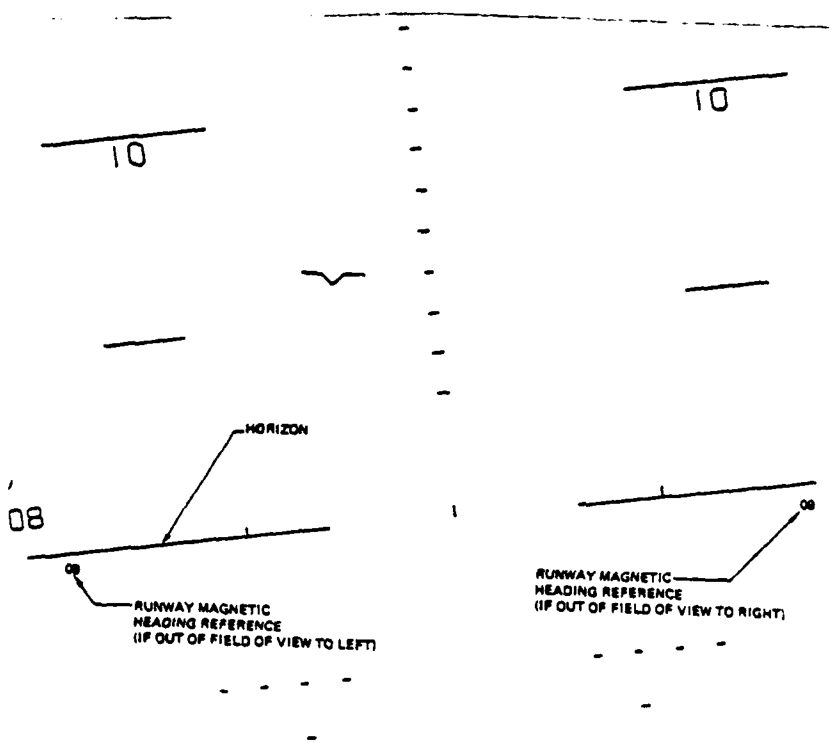


FIGURE D-2

indirectly controlling them through the more conventional control of pitch and roll attitude, heading, and vertical velocity and apparent track over the ground. Note that the lateral ground track feature described here is only available with the INS mode. Taking advantage of the flexibilities inherent in a CRT format, speed and altitude display elements are arrayed with the flightpath symbol in order to minimize the visual field encompassing all of the continuously controlled flight parameters. Three flightpath symbols and related elements are described in figures D-3, D-4, and D-5. The flightpath symbol array, shown in the context of aircraft attitude in figure D-6, includes flightpath, indicated airspeed, speed error, acceleration along the flightpath, and altitude. The distance between airspeed and altitude presentation is slightly larger in the aircraft HUD than in the simulation HUD.

2.3.1 Flightpath Symbols - In the aircraft, two flightpath symbols are available, depending on the flight mode selected. The IMC flightpath symbol is illustrated in figure D-3. This display element is a circle with short horizontal "wings." The center of the circle defines the direction of the flightpath. The VMC flightpath symbol is illustrated in figure D-4. This display element consists of two wedge-shaped wings which move together as a single unit. The center point between the wings defines the direction of the flightpath. Both of these symbols remain fixed in roll with reference to the aircraft. Two angles are represented in the wedge; 22 1/2 degrees closest to the flightpath center and 45 degrees on the other tips. These are sometimes useful in giving the pilot an indication of the aircraft nominal roll attitude. The flightpath symbol used in the simulation HUD is shown in figure D-5. The center of the circle defines the direction of the flightpath.

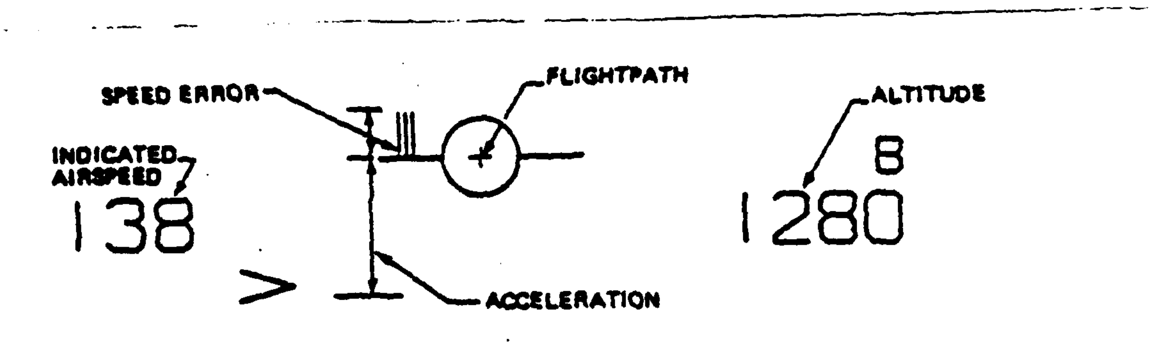


FIGURE D-3

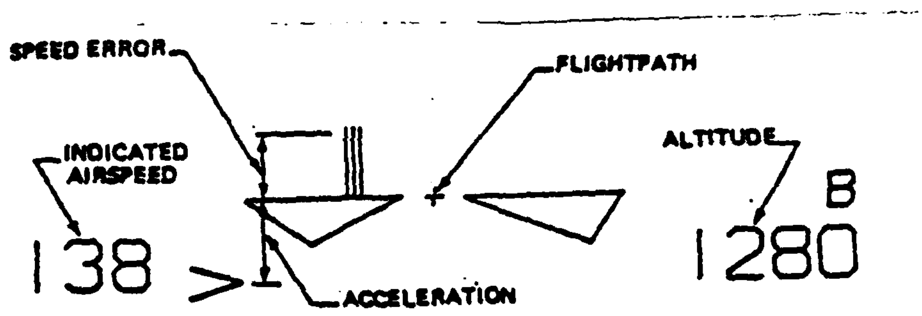


FIGURE D-4

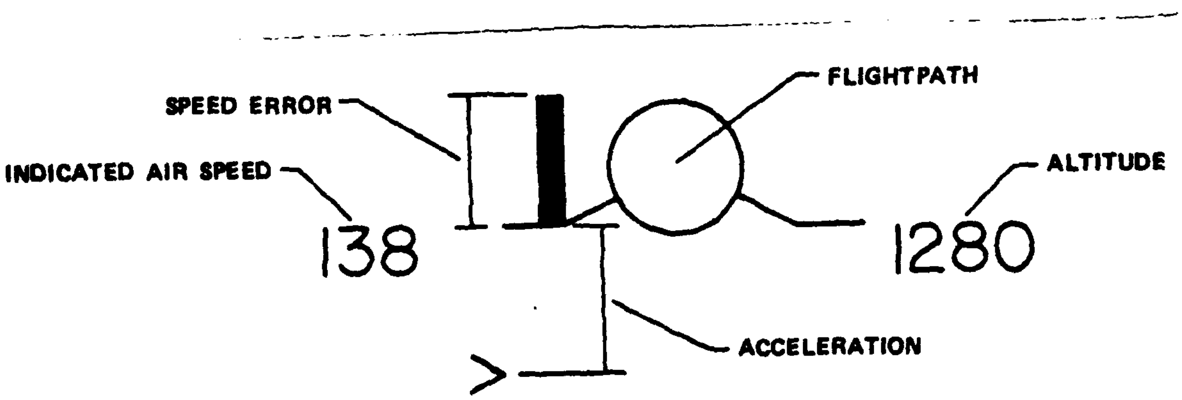


FIGURE D-5

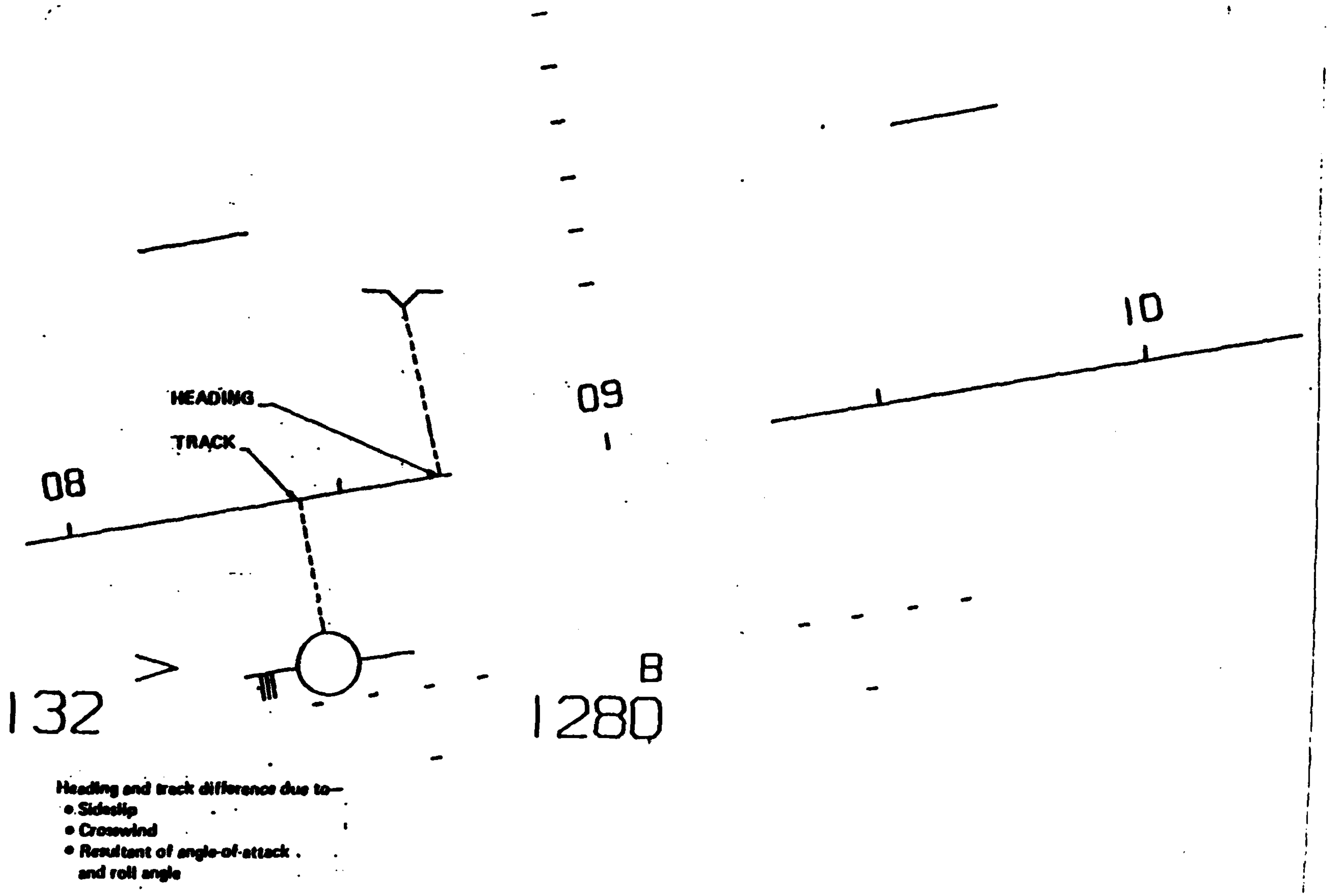

10
09
08
HEADING
TRACK
B
132
1280
Heading and track difference due to—
• Sideslip
• Crosswind
• Resultant of angle-of-attack and roll angle

FIGURE D-6

2.3.2 Indicated Airspeed - A digital presentation of indicated airspeed is located outboard and below the left "wing tip" of the flightpath symbol.

2.3.3 Speed Error - Deviation in indicated airspeed from a preset reference airspeed or deviation in groundspeed from a preset reference groundspeed is displayed by a tape extending vertically from the left tip of the flightpath symbol, upward for "fast," at a scaling of one degree subtended visual angle for four knots error and downward for slow at the same scaling. The deviation which has the minimum value will be the controlling speed error when in an inertial mode and a groundspeed reference is selected. Speed error is relative to IAS reference selected if the groundspeed reference is set to 0 or when in an AIRMASS configuration.

2.3.4 Acceleration Along Flightpath - Referenced to the left tip of the flightpath symbol is a chevron providing an indication of the acceleration along the flightpath of the aircraft. Flightpath acceleration is generated by resolving the three-axis body mounted accelerometer outputs along the direction of the flightpath vector. Appropriate scaling of the deflection of this symbol (approximately 3 degrees subtended angle per-knot-per-second) allows its interpretation as an indication of the flightpath angle that could be maintained, at constant speed, at the aircraft's current thrust and configuration. Earlier mechanizations of this concept have been termed "potential flightpath."

2.3.5 Altitude - A digital readout of altitude is located to the right of and below the right tip of the flightpath symbol. In normal operation, the digital readout represents main gear altitude above the terrain when aircraft altitude is less than the selected baro/radio (B/R) changeover altitude and the letter R (radio altitude) appears below the altitude readout. When aircraft altitude is more than the B/R changeover altitude the digital readout represents altitude above MSL, derived from air data reflecting QNH altimeter setting. In this latter case, the last digit of the altitude readout is always zero and the letter R is replaced with the letter B (barometric altitude) which appears above the altitude readout. In the simulator HUD, neither the B nor R indication is used. The readout simply indicates radio altitude at all times.

2.4 VOR/LOCALIZER NAVIGATION.

Aircraft position relative to the approach is proportional (at a given range from station) to the horizontal distance between the runway magnetic heading reference and the symbol segments shown. In the example shown in figure D-7, the aircraft is left of course and on a converging heading. This symbol is fixed vertically with reference to the horizon, its center element depressed below the horizon by an angle equal to the ILS glide slope angle. Lateral deflection of the symbol is limited to ±12.5 degrees from the boresight axis of the display. A "course line" symbol, as seen in figure D-8, originates at the horizon and is deflected right or left from the perpendicular to the horizon proportionally to the displacement from course. In the case shown, the aircraft is converging on a 090 degree course on a heading of 075 degrees. If the heading were maintained, the "localizer" symbol would move from left to right as the aircraft approached the localizer, seeking its zero-error position coincident with the runway magnetic heading reference indication (out of view to the right) and the "course line" would swing toward the perpendicular to the horizon. This movement of the localizer symbol begins when the aircraft comes within 2.5 degrees of the localizer. This movement is analogous to the movement of the localizer needle on a conventional HSI. However, due to software problems discovered too late to be corrected, the implementation

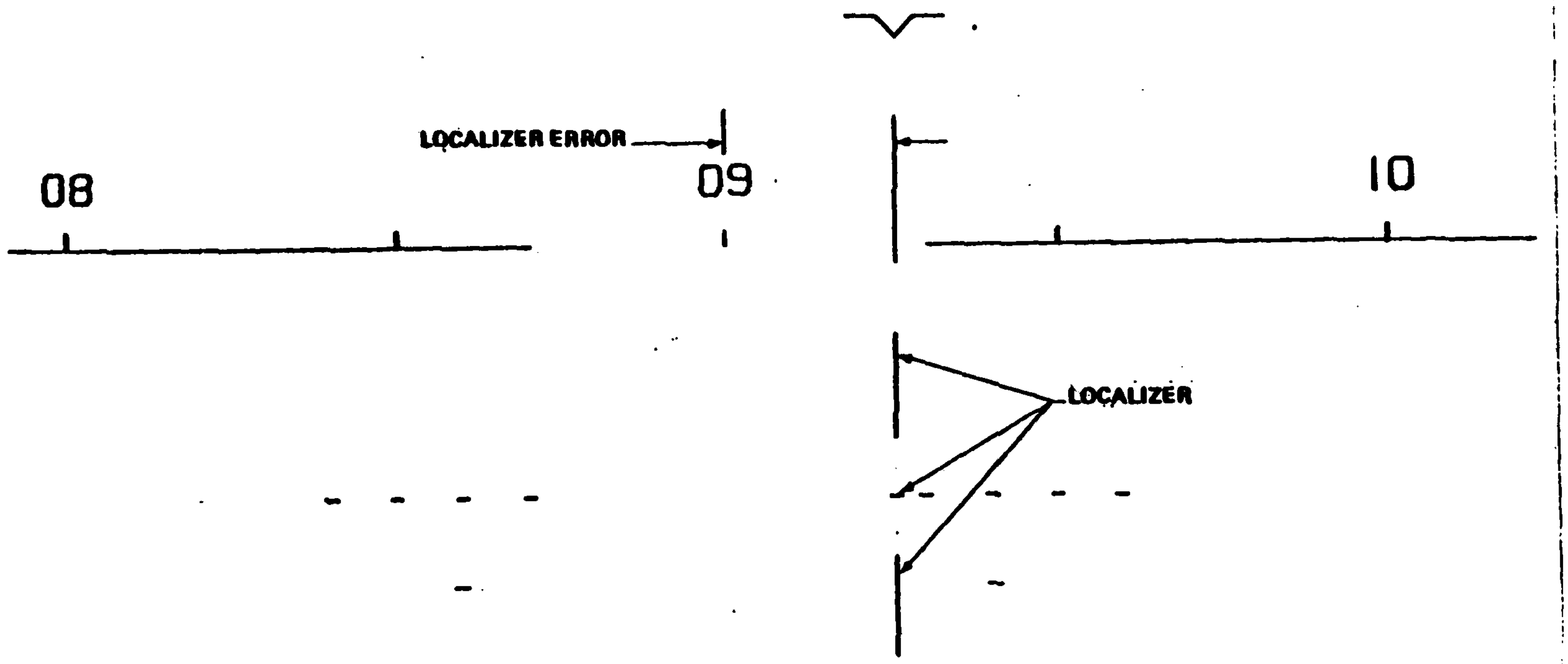


FIGURE D-7

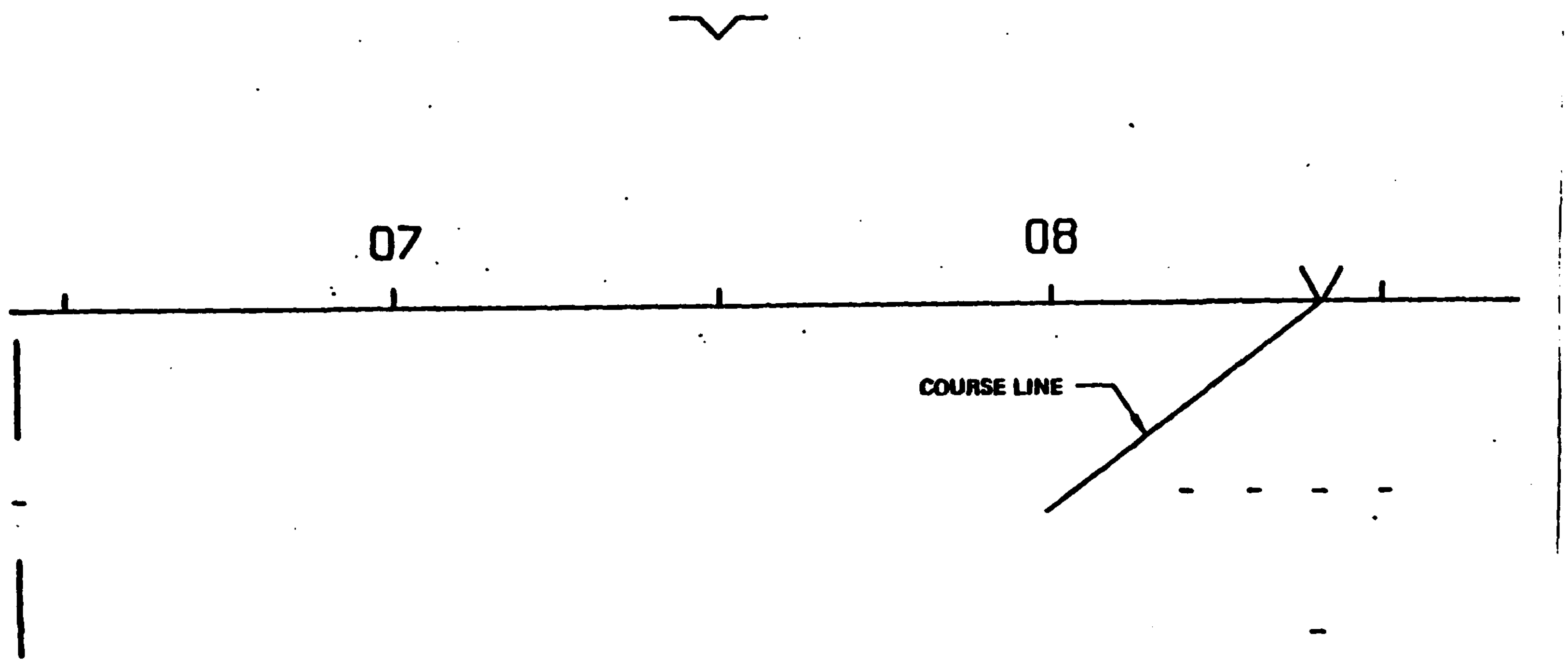


FIGURE D-8

of the localizer presentation was incorrect in the aircraft HUD. During a localizer intercept, instead of the localizer symbol being placed as indicated in figure D-8, it remained beneath the course line until the aircraft came within the 2.5 degrees of the localizer centerline and then jumped into the middle of the display, followed then by the correct movement back toward the desired course. Also, instead of the localizer error being factored by a gain of 12, it was changed to a gain of 4 which resulted in a slow convergence to the proper course.

2.5 ILS GLIDE SLOPE.

In figure D-9, the indication of error from the ILS glide slope is added in the form of a small circle and two horizontal line segments centered laterally on the localizer symbol. Error from the ILS glidepath is proportional (at a given range from station) to the vertical distance between the "glide slope symbol" and its zero-error reference defined by the center of the localizer symbol and the gamma reference dashes previously identified. If the aircraft is below the ILS glidepath, the glide slope symbol appears above the reference.

2.6 RUNWAY SYMBOL.

ILS error signals and altitude above the runway are used to define the position of the synthetic runway and runway centerline. If all signals are accurate and attitude references are accurate, this symbol will overlay the actual runway when it is visible. The runway centerline extends only to the touchdown point. In figure D-10, a configuration of combined ILS symbols are shown, depicting the aircraft above and to the left of the ILS approach path. These sketches are intended to demonstrate the objective of the logic and scaling of the localizer and glide slope symbols. In perspective, as an analog of an exterior view, the intersection of these symbols denoted by the circle, can be perceived as an object on the ILS approach path some distance ahead of the viewers aircraft. In figure D-11, the flightpath symbol array is added in illustration of the normal mode of controlling the ILS approach. If the flightpath of the aircraft is maintained directed at the intersection circle, a pursuit course, converging on the ILS path, will be flown. The ultimate result will be the condition illustrated in figure D-12 in which the viewer's aircraft can be perceived as being in trail behind the circle, on the ILS path while moving toward the touchdown point.

In the simulator HUD, the sides of the synthetic runway did not extend to the horizon, being cut off about a third of the way down the runway and there was no centerline.

2.7 REREKENCE ALTITUDE SYMBOL.

The selection of a reference altitude is available in HUD configurations not displaying ILS glide slope information. The symbol illustrated in figure D-13 is available for use in the annunciation and capture of a preselected target altitude. The distance of the symbol below the horizon is proportional to the aircraft's altitude above the reference altitude. In the illustration, the aircraft is descending on a five degree flightpath toward a target altitude (MDA) of 450 feet. Tracking the symbol with the flightpath symbol to the horizon will result in level flight at 450 feet. Again, the analogy of flying in trail behind another aircraft is seen, but this time it is in level flight. The altitude reference will represent barometric altitude (MSL) when its value is greater than the B/R changeover altitude and radio altitude (AGL) when less than the B/R altitude.

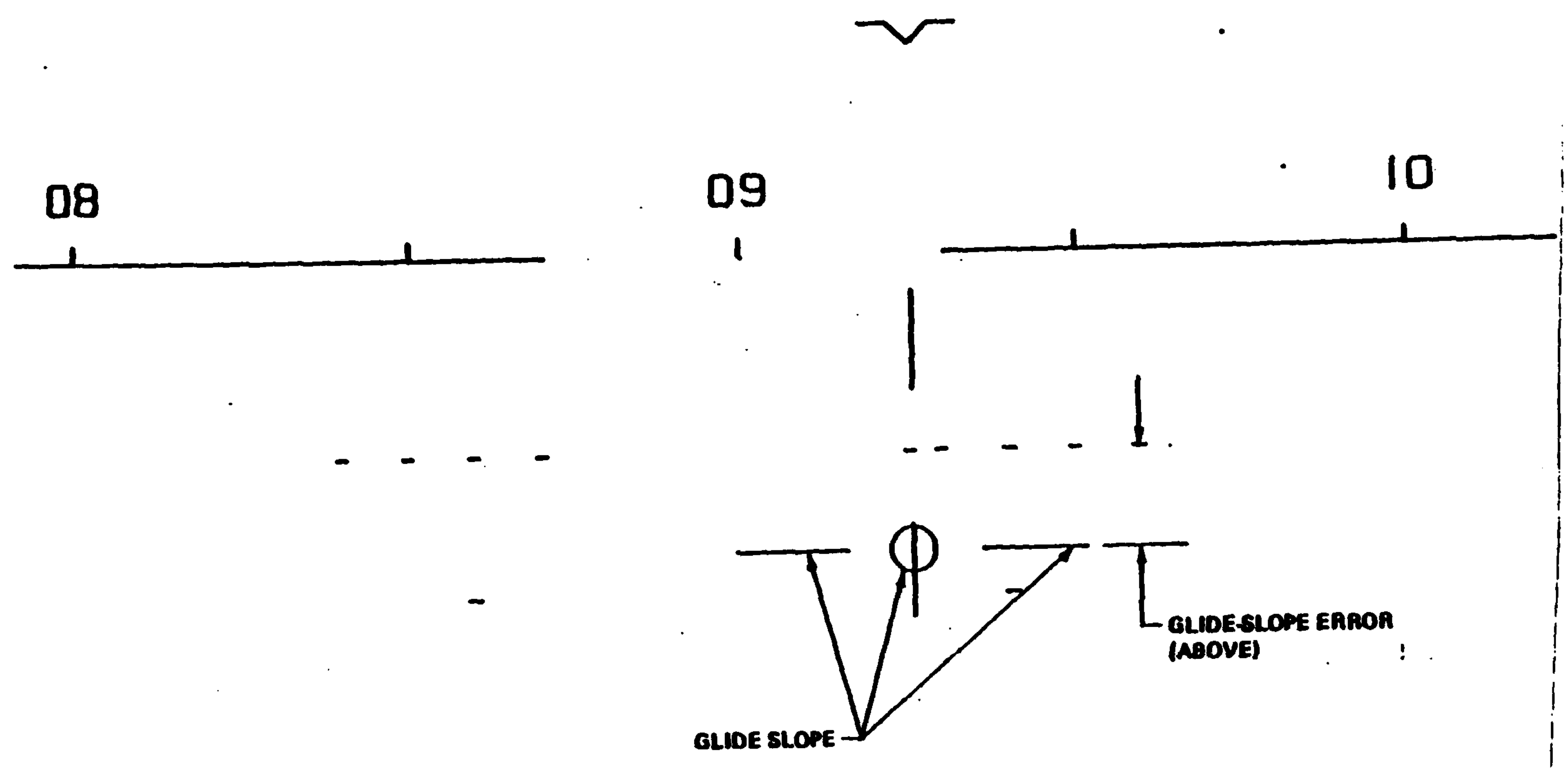
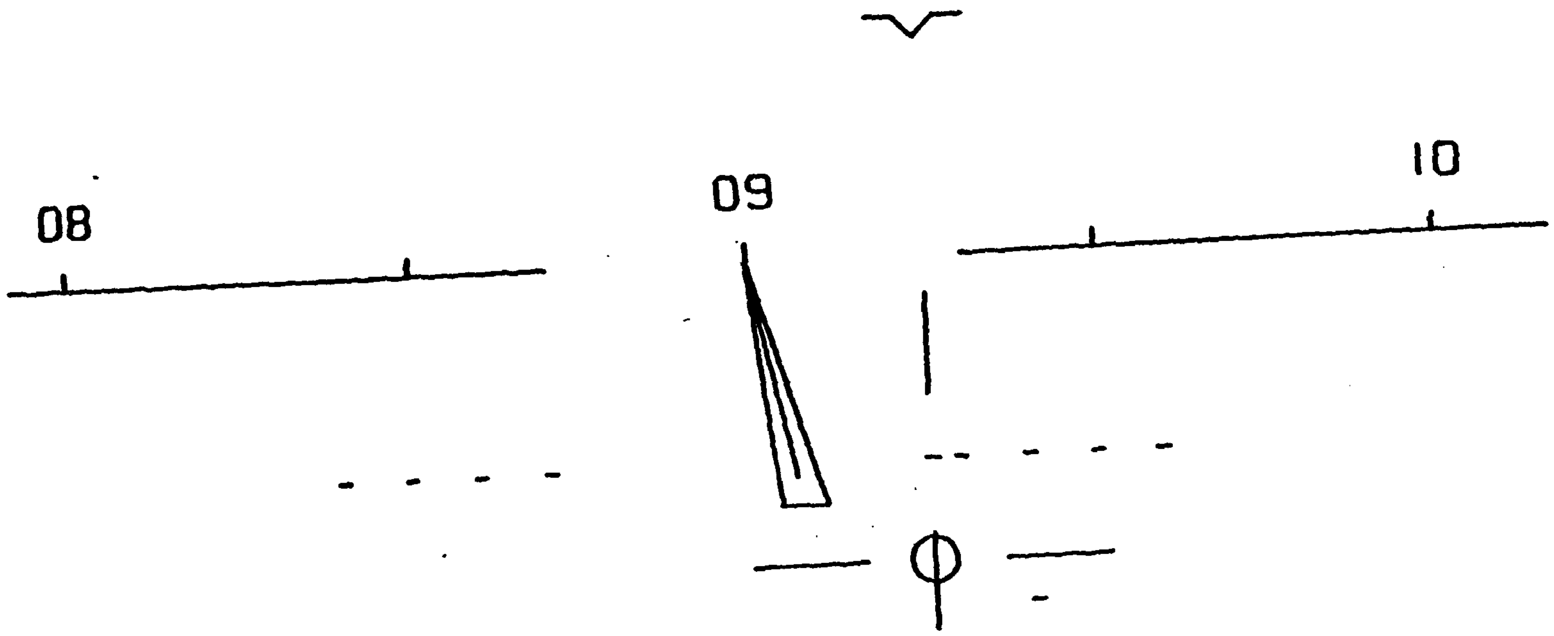


FIGURE D-9



ABOVE AND LEFT OF PATH, 2.8 mi
FROM RUNWAY

FIGURE D-10

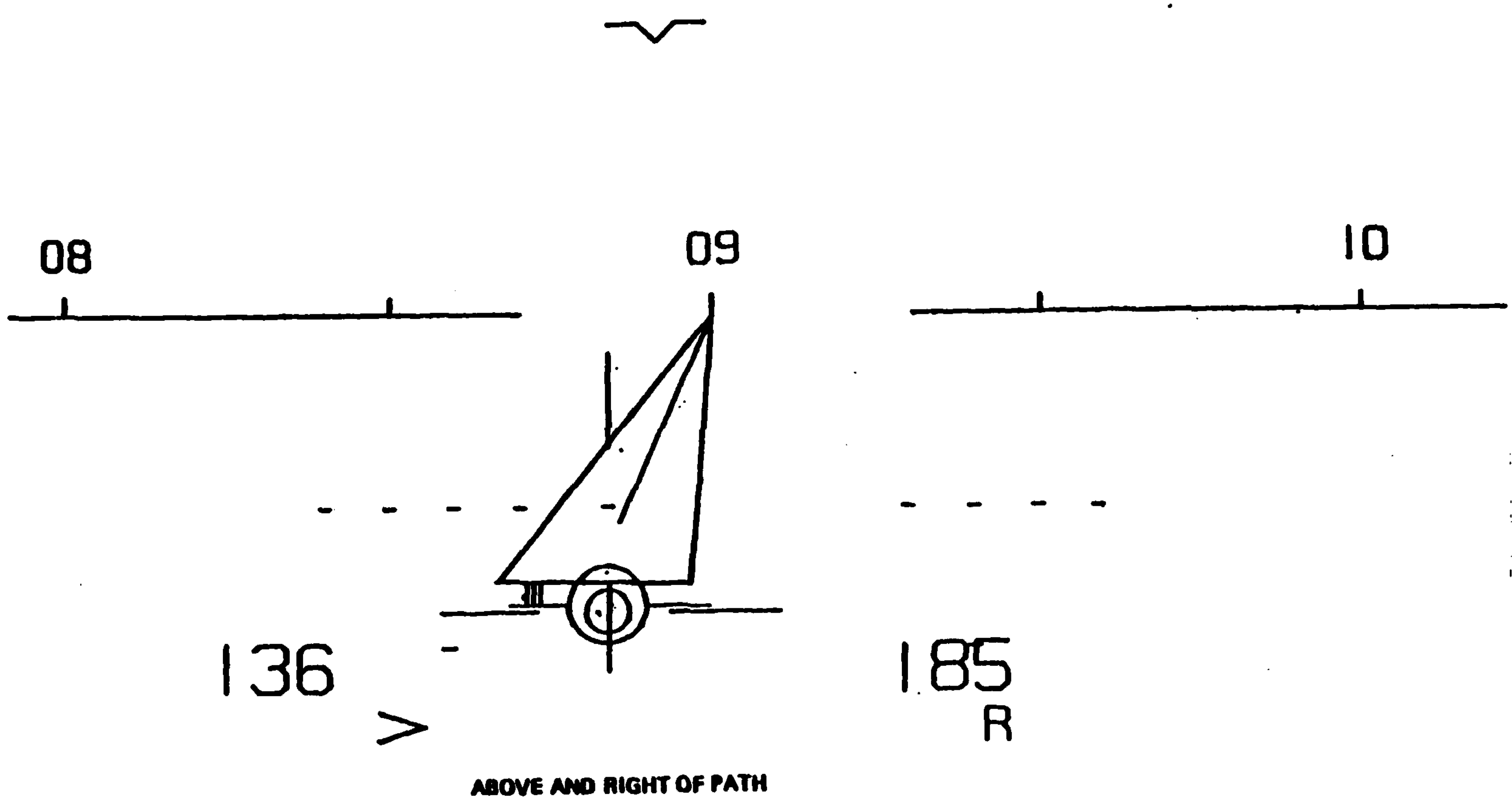
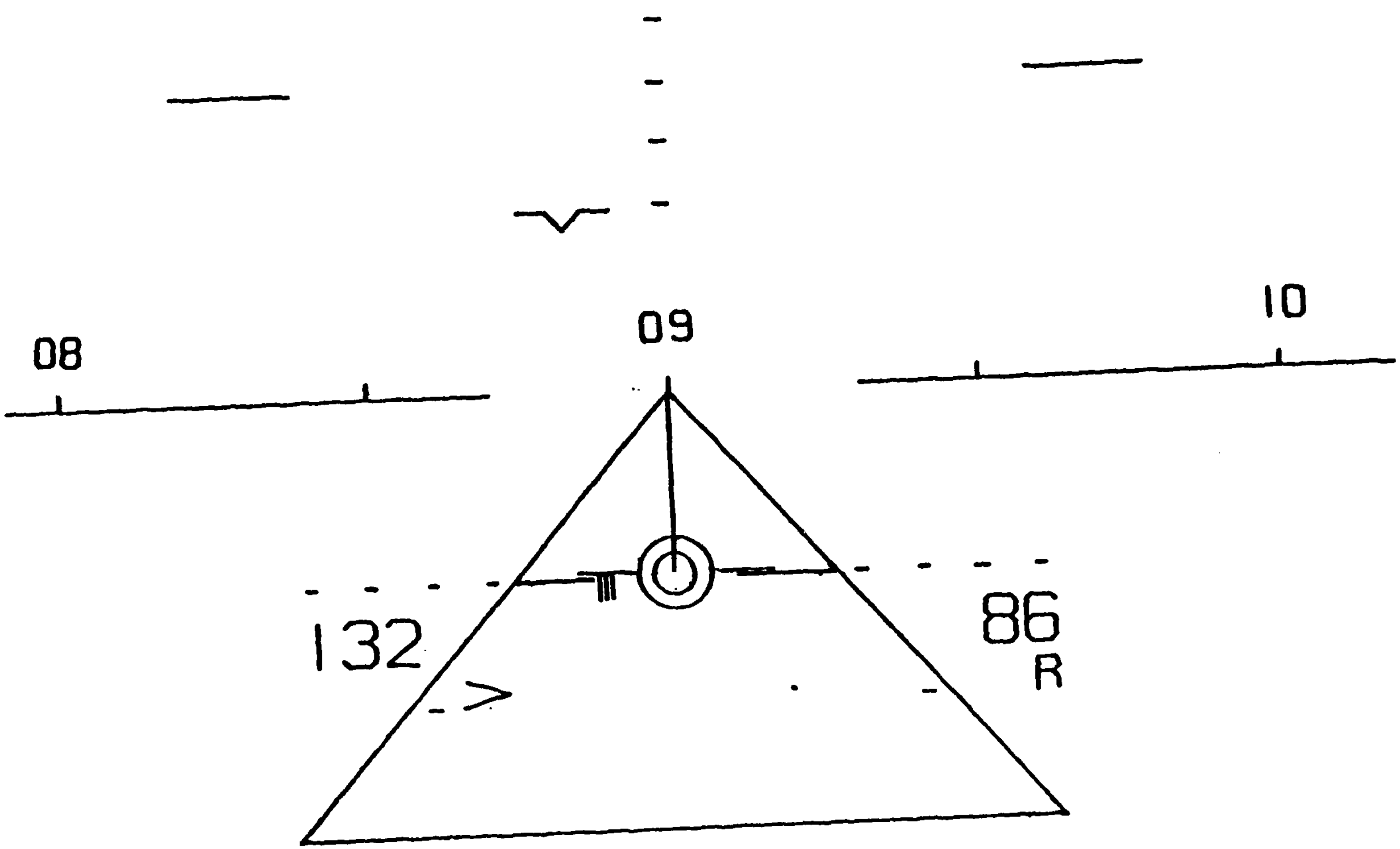


FIGURE D-11



ON PATH, 1,000 ft FROM THRESHOLD

FIGURE D-12

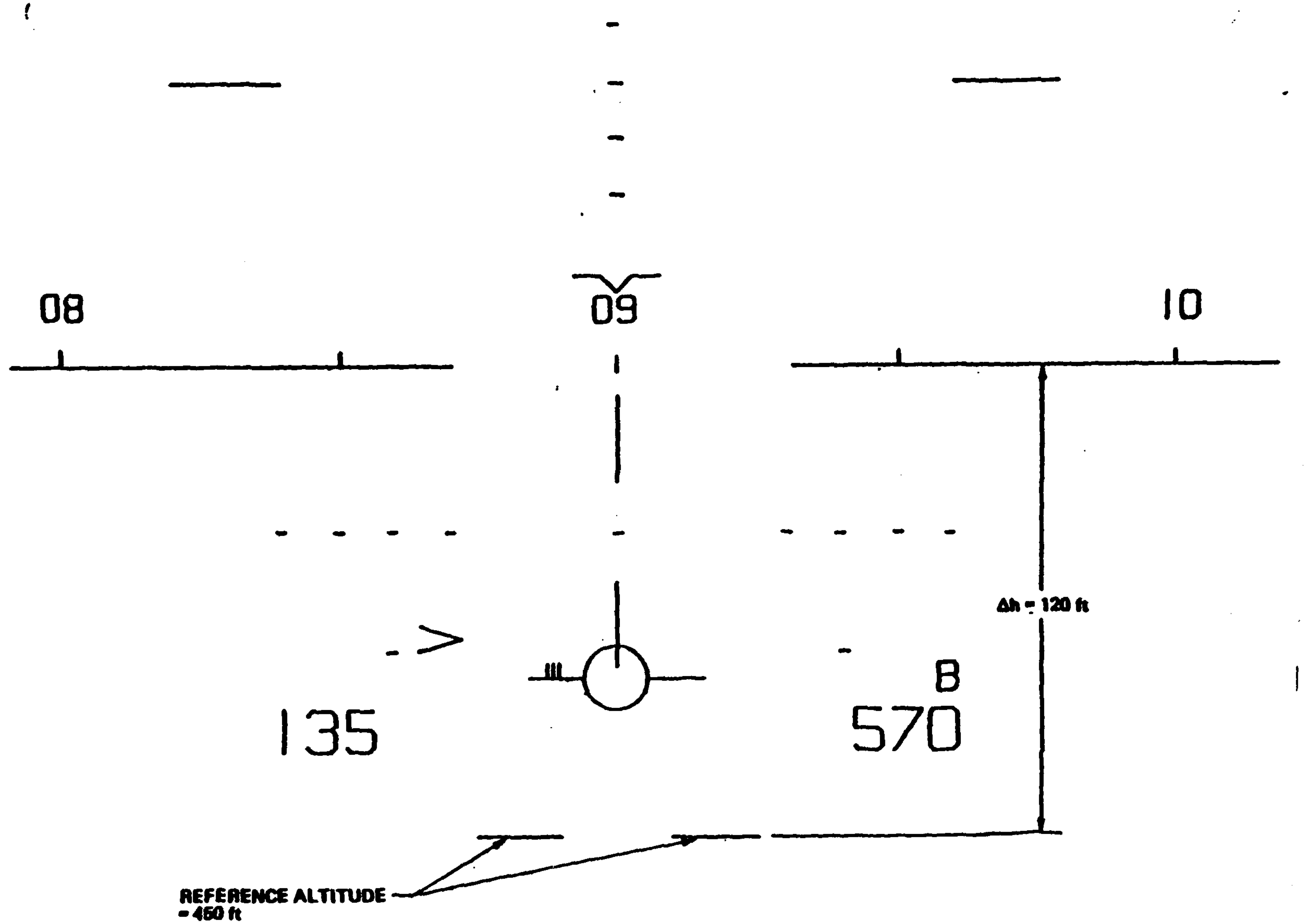


FIGURE D-13

2.8 FLARE SYMBOL.

A symbol similar in geometry and operating principle to that of the reference altitude symbol is provided as a landing flare flightpath guide. In this case, the symbol is displayed below the horizon a distance proportional to radio altitude measurement of main gear height above the runway. In figure D-14, the symbol is shown rising from the bottom of the display as flare altitude is approached. In figure D-15, the "flare" symbol is being tracked with flight path to achieve a rotation to establish a landing attitude at touchdown.

2.9 TAKEOFF REFERENCE SYMBOL.

In the TO/GA mode, this symbol provides runway heading guidance with a vertical line (perpendicular to horizon) emanating from the horizon at the selected runway heading. Figure D-16 shows the aircraft reference symbol depressed below the horizon reference about 1 degree during a takeoff roll. Reference airspeed is selected prior to the takeoff roll and the speed error decreases in magnitude as the airplane accelerates to V_{ref}.

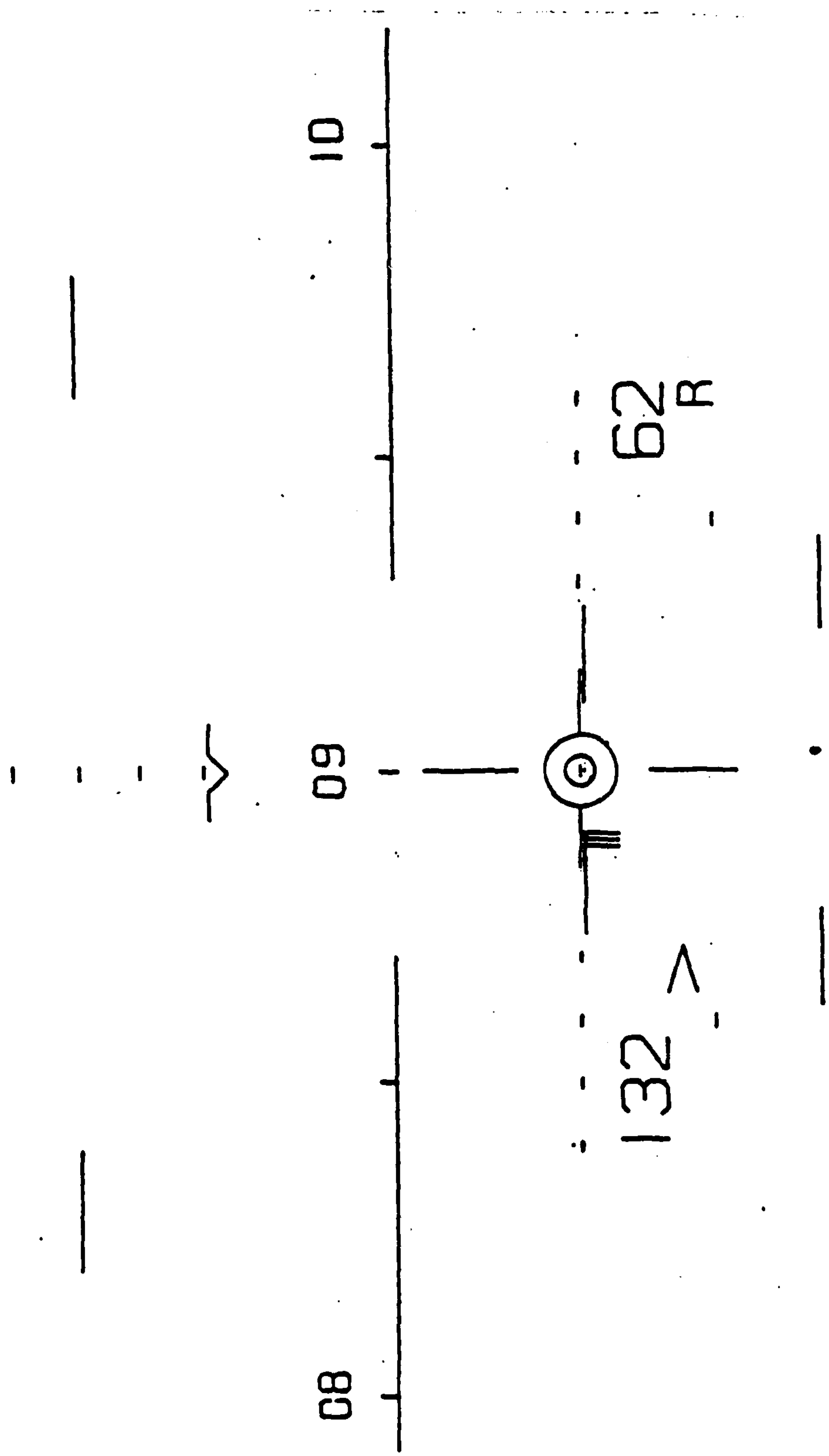


FIGURE D-14

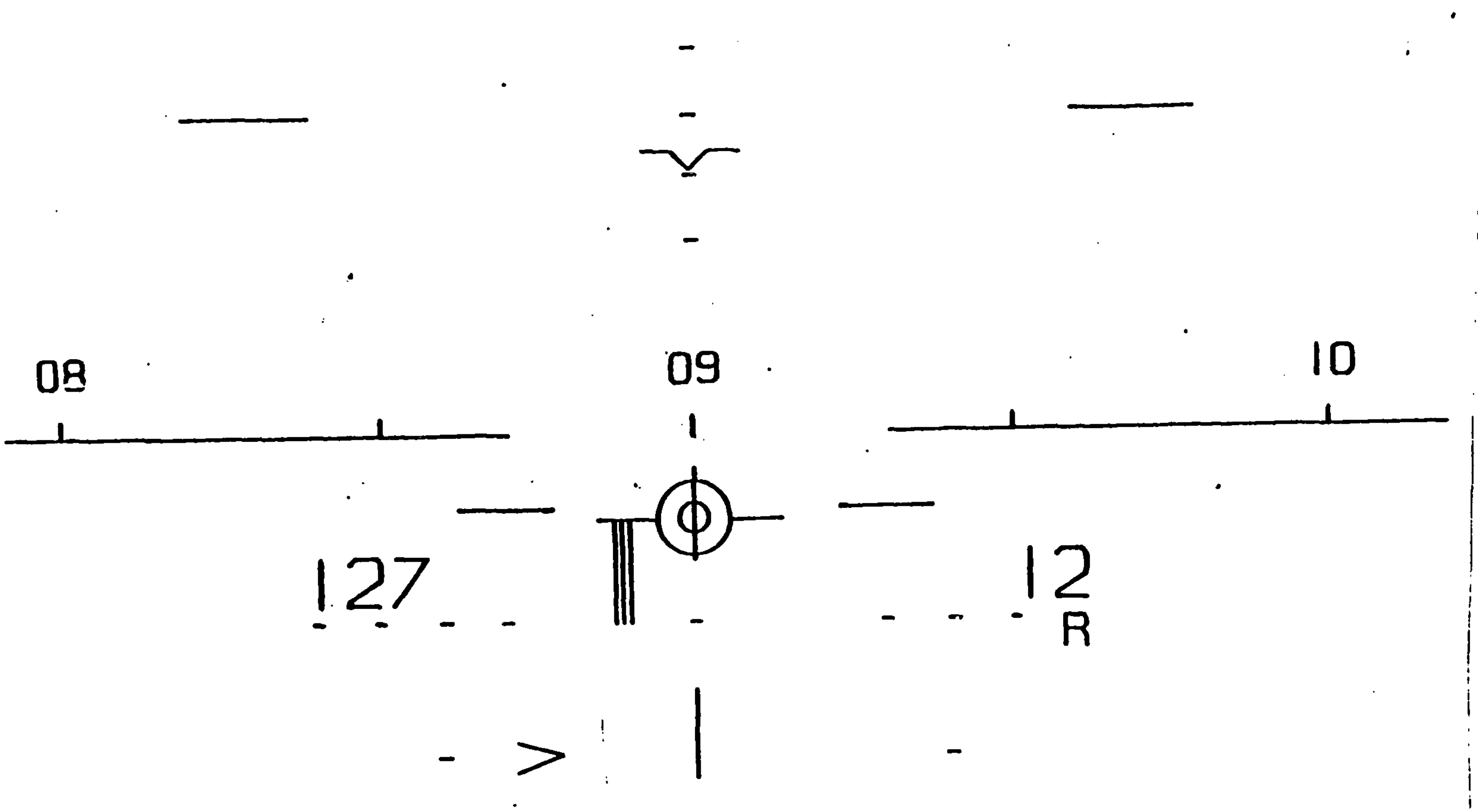


FIGURE D-15

APPENDIX E

FAA BOEING 727 HEAD-UP DISPLAY INSTALLATION

BORESIGHT AND SCALING CHECK PROCEDURES

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 Introduction

This recommended procedure addresses the critical portion of the HUD installation procedure associated with aligning the HUD with the aircraft primary structural axes.

The importance of establishing and maintaining proper alignment in the aircraft cannot be overstated.

It is recommended that the reader review all figures and references at this time.

2.0 Setting HUD Boresight Elevation and Azimuth

2.1 Preparation for Boresighting

2.1.1 Locate the aircraft in a position suitable for jacking and leveling operations and that will allow placement of an aerostand with targetboard 300 ft. in front of the aircraft. An unobstructed view between the two will be required.

2.1.2 Assemble and fabricate all necessary equipment by reference to figures 1 through 6 and after reviewing this text.

2.1.3 Level the aircraft according to reference (2).

2.1.4 Refer to figure 1. This figure shows a plan view of the aircraft and indicates a reference point "AA" located slightly below and just aft of the rear cockpit window, left side. Now refer to figure 2. This figure shows the detailed location of point AA which is the particular rivet shown at Body Station 259.5 and Waterline 232.5. Affix a flexible measuring tape to the skin of the airplane with one of the graduation marks level with the center of the rivet at AA. See figure 3. Locate engineers transit so as to be behind measuring tape (freely hanging) and sighting forward of the airplane. Set transit for 0^0 elevation with the elevation on a primary graduation mark on the tape.

2.1.5 Still referring to figure 3, locate aerostand in a position 300' ahead of pilot Eye Reference Point (ERP). Mount the target board to the aerostand in such a manner as to be able to rotate it to a level attitude in roll. At this time, refer to figure 6 for detailed target board specifications. Note recommended paint scheme as the target board crosshairs will be difficult to see at 300'. Also note that the aerostand must be adjustable vertically and capable of being translated horizontally for positioning the target board. Affix another flexible measuring tape to the target board such that a primary graduation mark is over the intersection of the crosshairs. (Note: both measuring tapes should be hanging reasonably taught).

2.1.6 Still referring to figure 3, take a level sighting from the measuring tape from AA to the measuring tape from the target board center. Determine distance "a" by reading the difference from AA to the transit sight level. Add 21.04" to "a" and note the sum. Now raise or lower the aerostand as required such that the target board center is (a + 21.04) higher than the level sighting line. This procedure will place the target board center on a plane equal to W/L. 253.54, the ERP height.

2.1.7 At this time, refer to figure 4A. Make two distinguishable marks on (1) the upper fuselage centerline (Buttock Line 0) (2) on the upper engine inlet cowling centerline (Buttock Line 0). Determine the fore/aft location of (1) by looking at the airplane head-on at a distance that will co-align the upper fuselage curvature and the upper intake cowling at a height convenient for a transit sighting. This position relative to the aircraft will be approximately 150' ahead of the airplane. Locate the transit and adjust its position until the two marks ("A" and "B") and the transit vertical crosshair are coincident. Locate two stanchions along this line of sight. These two stanchions are now coincident with the aircraft Buttock Line 0 plane.

2.1.8 Now refer to figure 4B. Move the transit to the position in figure 4B, only now sighting forward relative to the aircraft. Align the transit vertical line with the two stanchions C and D. Now move the aerostand and/or the target board left or right until the center is 21 inches left of the stanchion sighting line. This procedure establishes the target centerline at left buttock line 21.0 (ERP buttock line). Check vertical crosshair with plumbline.

2.1.9 Re-check the elevation of the target board as in 2.1.6.

2.1.10 The target board center is now in position for boresighting.

2.1.11 Again refer to figure 48. Locate two stanchions as shown 50 ft either side of the targetboard vertical centerline. These two stanchions should be high enough to enable placement of a brightly colered object (such as a dayglow colored ribbon) on a level with the horizontal crosshair. Mount the bright objects on a level sighting with the targetboard horizontal crosshair. These two objects form an extended horizontal centerline that will allow roll boresight adjustment.

2.2 Boresighting Procedure

2.2.1 With the aircraft and target board positioned as in 2.1, prepare to adjust boresight as follows:

(a) Adjust electronic boresight potentiometers on HUD drive electronics panel (in overhead switch panel of cockpit) such that they are centered in their adjustment range.

(b) By reference to (1), locate azimuth adjustment screws on HUD mounting assembly. These are the 4 screws that hold the mounting assembly to the aluminum replacement eyebrow window.

(c) Turn HUD power on and switch to "test" position.

(d) Bring up symbol generator and all required instrumentation sensors.

2.2.2 With 4 mounting screws loosened, physically rotate HUD assembly left or right in yaw as required to place the vertical test crosshair coincident with target board center. Switch to normal position of video switch with symbol generator symbology showing in HUD. Re-check yaw positioning of reference aircraft symbol (—⋎—). It should be on the vertical crosshair of the target board (figure 6). If it is not, the symbol generator is not functioning properly. This establishes the mechanical yaw boresight position. Tighten the 4 screws on the mounting assembly. Re-check yaw boresight and if necessary, make fine adjustment on the "X" potentiometer on the HUD drive electronics panel.

2.2.3 Locate pitch and roll adjustment screws and follow up linkage by reference to (1). With follow up linkage loosened, adjust pitch until the reference aircraft symbol is coincident with the target board horizontal crosshair. Also make adjustment of roll to assure reference aircraft is level relative to target board. Tighten down all pitch and roll follow up linkages. Re-check horizontal and vertical positioning of reference aircraft to assure that roll adjustment did not change boresight. If this happened, make final fine adjustments of both "X" and "Y" potentiometers until boresight is on center. This establishes the mechanical pitch and yaw adjustments - they should not need changing again. From this point on, all pitch and yaw adjustments should be well within the range of potentiometer adjustment.

CAUTION

If, on subsequent boresight checks, either "X" or "Y" potentiometer adjustment is not near its center position, a total mechanical boresight must be re-accomplished (e.g., 2.1 through 2.2). If this is not observed, the available field of view will be drastically reduced in one or more quadrants, and the symbology scaling relative to the outside world will be in error.

3.0 Scaling Check Procedures

3.1 Preparation for Scaling Check and Fine Adjustment in Roll

3.1.1 Make sure aircraft is still leveled as in 2.1.3.

3.1.2 Locate aerostand and target board as in figure 5.

(a) Assure target board is precisely 35 ft ahead of pilot eye reference point. (STA 228.0).

(b) With HUD turned on, adjust elevation and azimuth of target board such that the center is coincident with the HUD reference aircraft symbol (—v—).

(c) Level the target board with a plumbline.

(d) Re-check elevation and azimuth of target board.

(e) Re-check level positon of target board with plumbline.

The target board should now be in position for scaling, and pincushion adjustments.

3.2 Set Θ, , Ø equal to zero with the symbol generator. This should align HUD symbology vertically and horizontally and zero reference frame displacements relative to reference aircraft symbol.

3.2.1 Check that horizontal center reference (e.g., horizon line) on HUD symbology overlies the horizontal crosshair on the target board.

3.2.2 Pincushion checks should be done at this time. If any curvature exists toward the extremities of the horizon line or any other symbology, these must be adjusted on circuit boards inside the HUD drive electronics box.

3.2.3 Scaling checks can now be made. These checks are accomplished by checking that the $\pm 5^0$ heading marks along the horizon line overlie the appropriate 5^0 gridlines on the target board (see figure 6). Also check $\pm 5^0$ pitch lines coincident with their respective 5^0 gridlines on the target board (see figure 6). Adjustments to horizontal and vertical scaling are in the HUD drive electronics box. Only a qualified technician familiar with the circuits should attempt these adjustments (e.g., scaling and pincushion).

3.2.4 Switch HUD video switch to "Test" and varify that the vertical test crosshair is coincident with the vertical target crosshair. Check that the horizontal test crosshair is coincident with the 6 degree gridline at the lower edge of the target board (see figure 6). If these two crosshairs are not in this position, the center of the CRT is misaligned or the symbol generator is not operating properly.

4.0 Final Boresight Adjustment and Recurrent Boresight Check.

4.1 If any adjustments were made to scaling or pincushion, or any adjustments were made to boresight, or on a recurrent basis, accomplish the following. 3.0 should only be re-accomplished if there is strong reason to suspect that the HUD has drifted off in scaling.

4.1.1 Repeat section 2.1

4.1.2 Repeat 2.2.1, (d) and select "NORM" on video selector on HUD drive box.

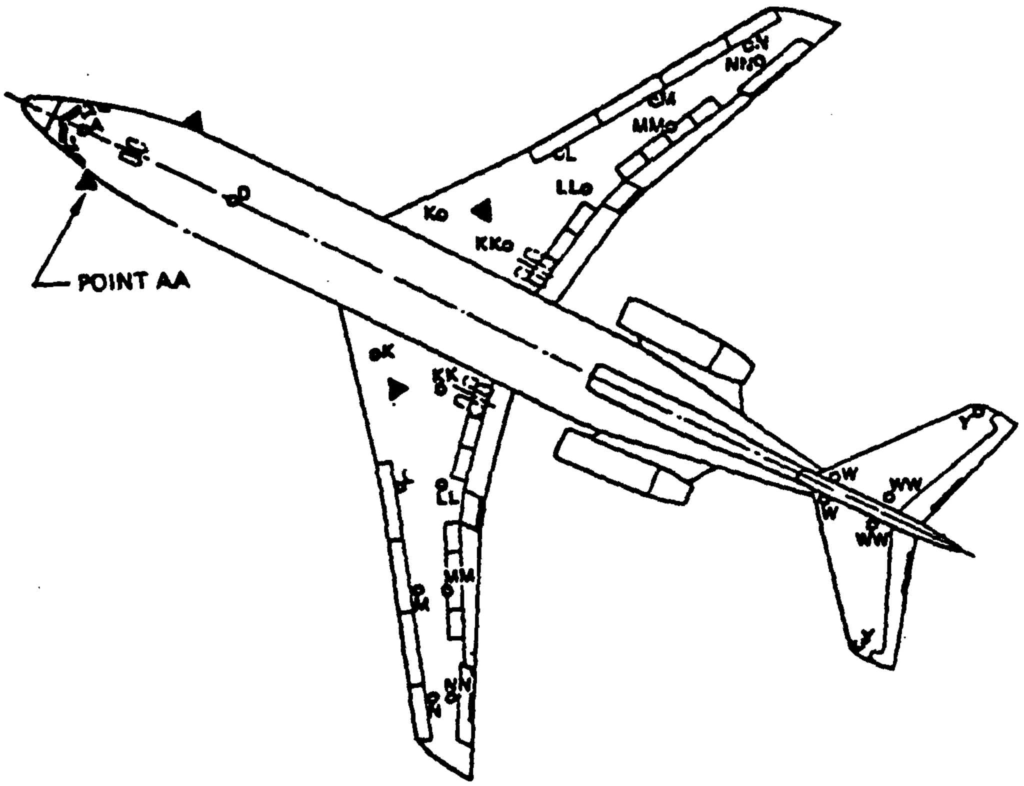
4.1.3 Check reference aircraft symbol (—γ—) coincident with target board center. Adjust "X" and "Y" potentiometers on HUD drive box as necessary to center the symbol. (Refer to "CAUTION" under 2.2.3. Otherwise, do not tamper with any of the mechanical adjustments).

4.1.4 Return aircraft and systems to normal operation.

References:

1. Sundstrand Data Control, Inc., Drawing #964-0278-201 (sheets 1 & 2), "Outline Drawing - 727 HUD Mounting Assembly".

2. Boeing Document D6-4062, "727 Structural Repair Manual", Chapter 51-60.



O Point on lower surface of airplane

▲ Location of point AA (sec. 41)

▲ Location of jack

FIGURE E-1. ALIGNMENT POINT AA-PLAN VIEW

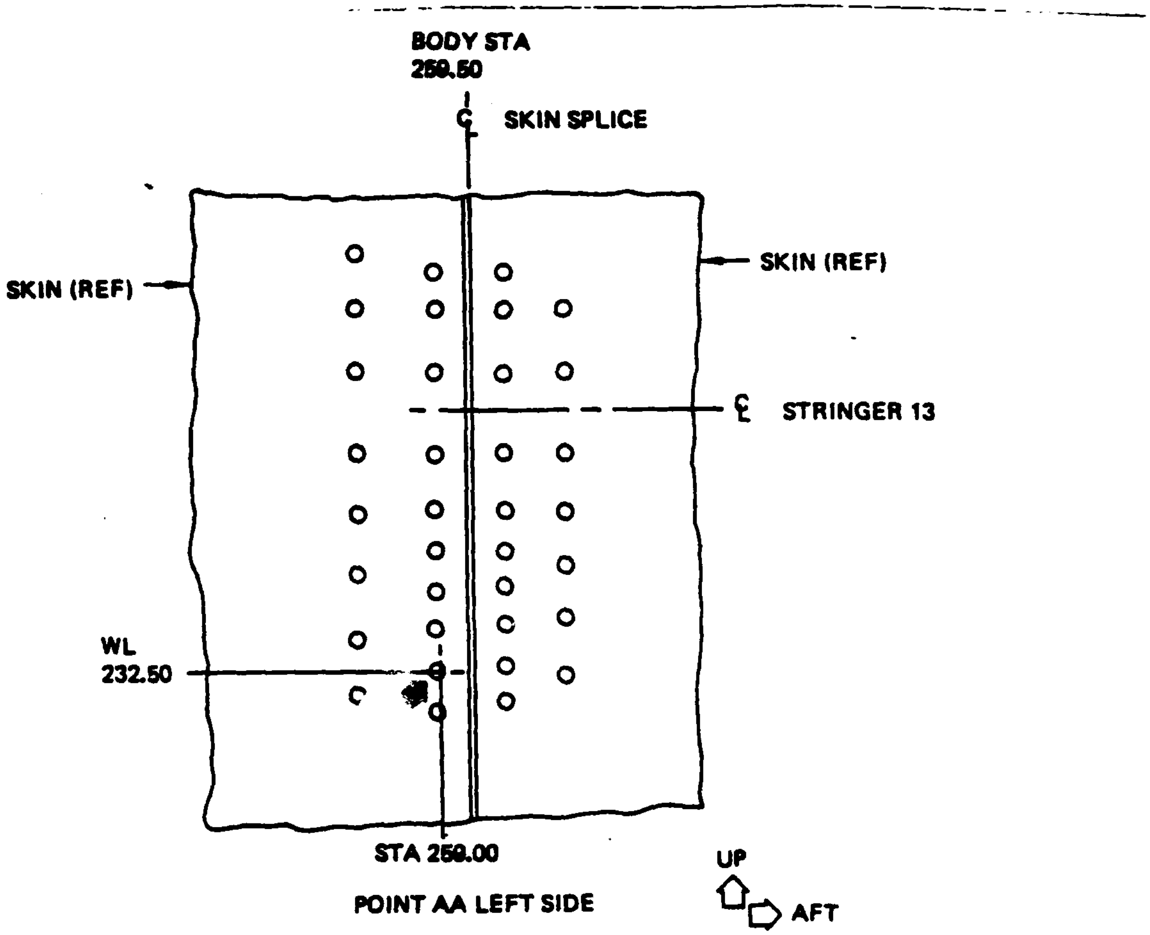
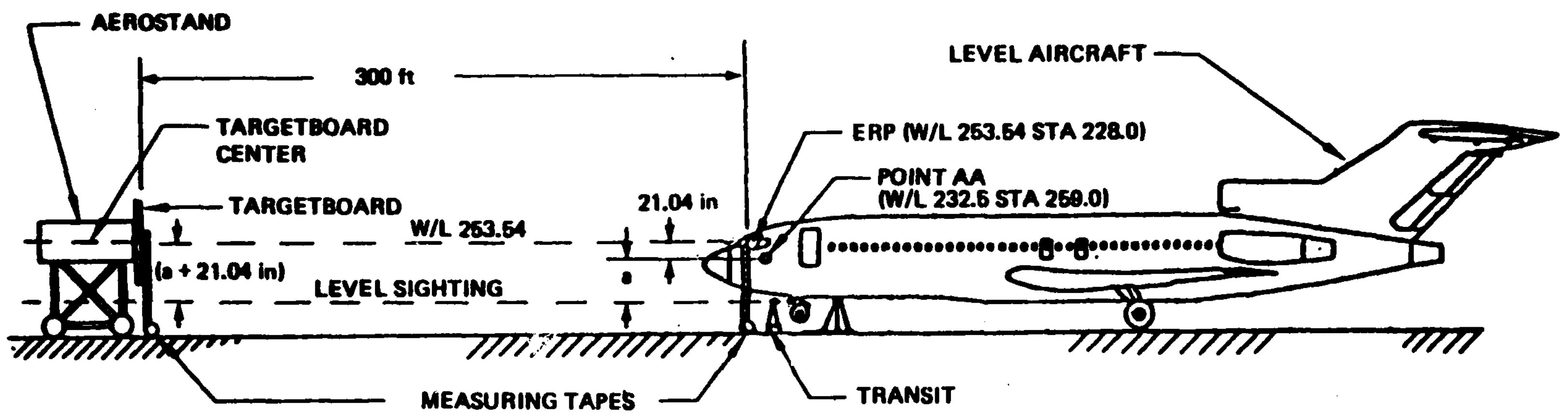


FIGURE E-2. ALIGNMENT POINT AA-DETAIL VIEW



ERP	Eye reference point
AA	Reference location on fuselage skin (figs. 1 and 2)
a	Any convenient distance placing transit at confortable height; measured at time o' sighting
Targetboard	See figure 6 for detail

FIGURE E-3. ESTABLISHMENT OF TARGETBOARD ELEVATION AT 300-FT RANGE

AD-A138 699 INSTALLATION VALIDATION AND FLIGHT EVALUATION OF THE FEDERAL AVIATION ADM..(U) FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT..

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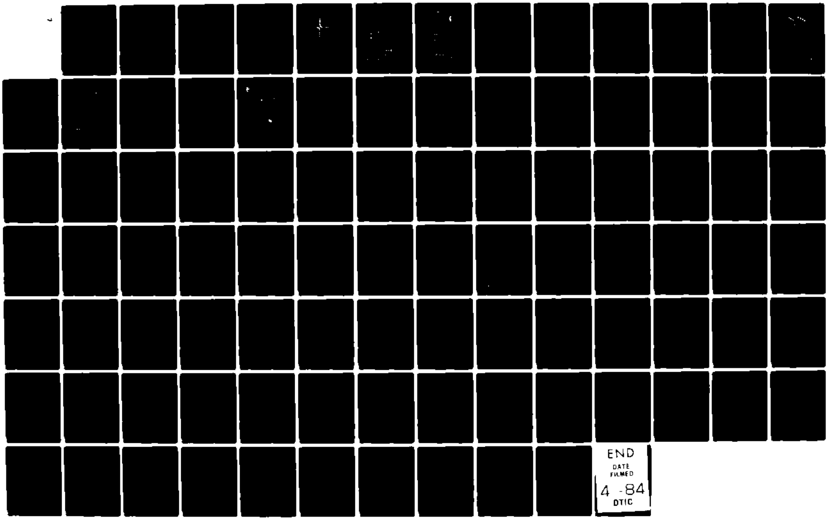
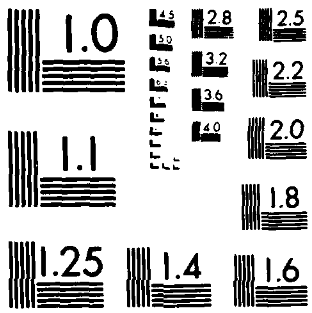
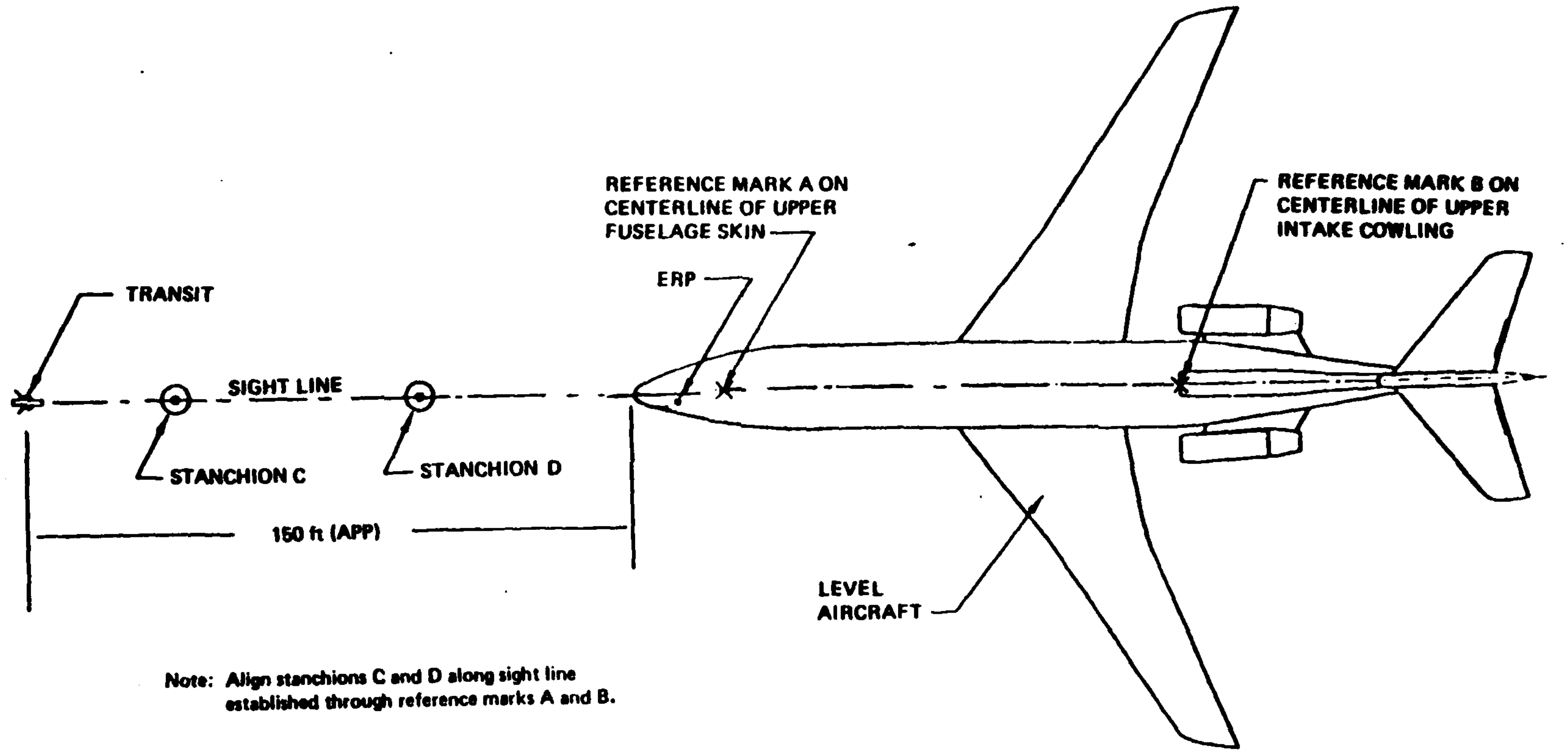




MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A



Note: Align stanchions C and D along sight line established through reference marks A and B.

FIGURE E-4. ESTABLISHMENT OF TARGETBOARD AZIMUTH AT 300 FT (Page 1 of 2)

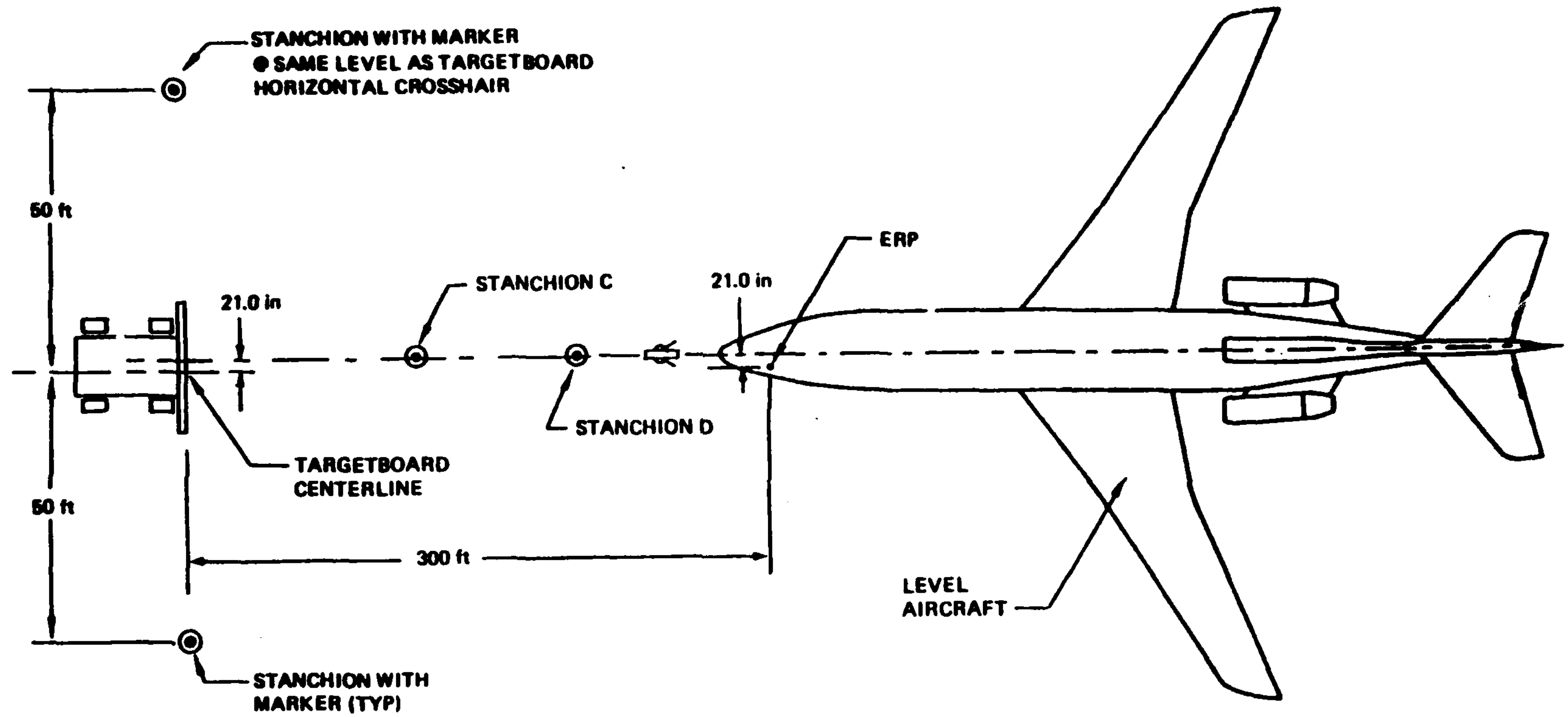
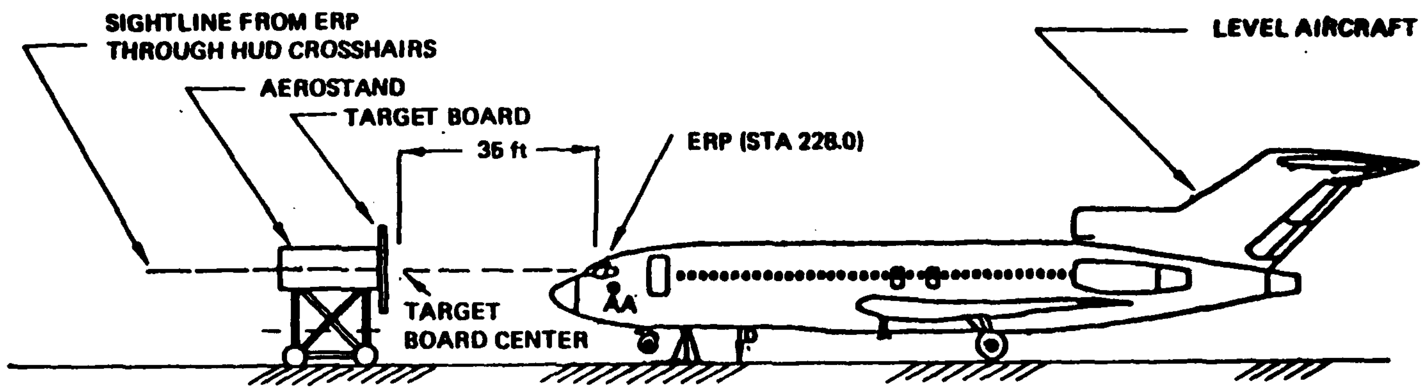


FIGURE E-4. ESTABLISHMENT OF TARGETBOARD AZIMUTH AT 300 FT (CONCLUDED)
(Page 2 of 2)

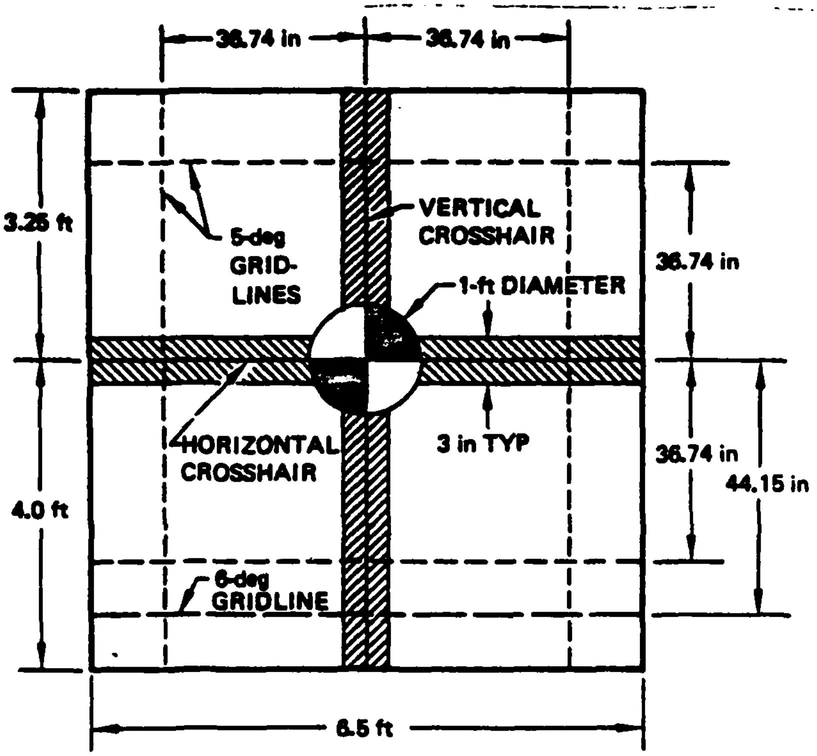


Note:

Postion targetboard such that–

- Front surface is 35 ft ahead of ERP
- Elevation and azimuth of target board center are established by reference to HUD crosshairs.
- Rotational position is established by aligning vertical targetboard crosshair with plumb line.

FIGURE E-5. POSITIONING OF TARGETBOARD FOR SCALING AND PINCUSHION CHECKS



Notes:

- Targetboard is constructed of plywood or other stiff sheet material.
- Recommend drilling large-diameter holes over most of the surface to minimize the effect of winds blowing on the targetboard.
- Recommend that horizontal and vertical crosshairs be wide (3 in) lines painted with very bright paint, and/or high contrast to background (e.g., dayglow against white). Also paint fine, precise centerlines on these 3-in stripes. Other gridlines can be fine lines.
- Fabricate some means of attaching board to aerostand such that it can be rotated. Aerostand must be adjustable vertically and movable horizontally (e.g., on casters).

FIGURE E-6. TARGETBOARD SPECIFICIATIONS

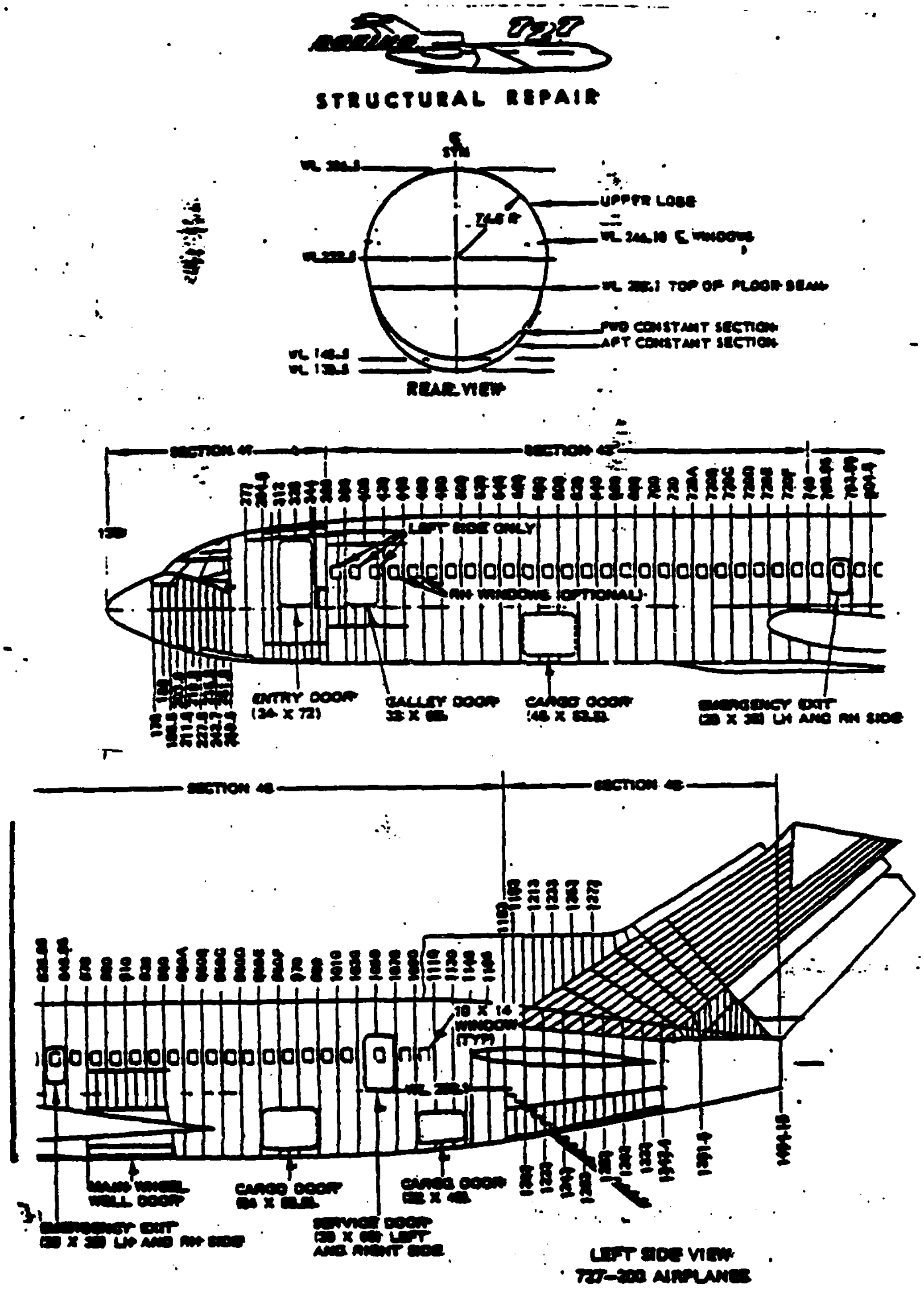


FIGURE E-7. FUSELAGE STATION DIAGRAM

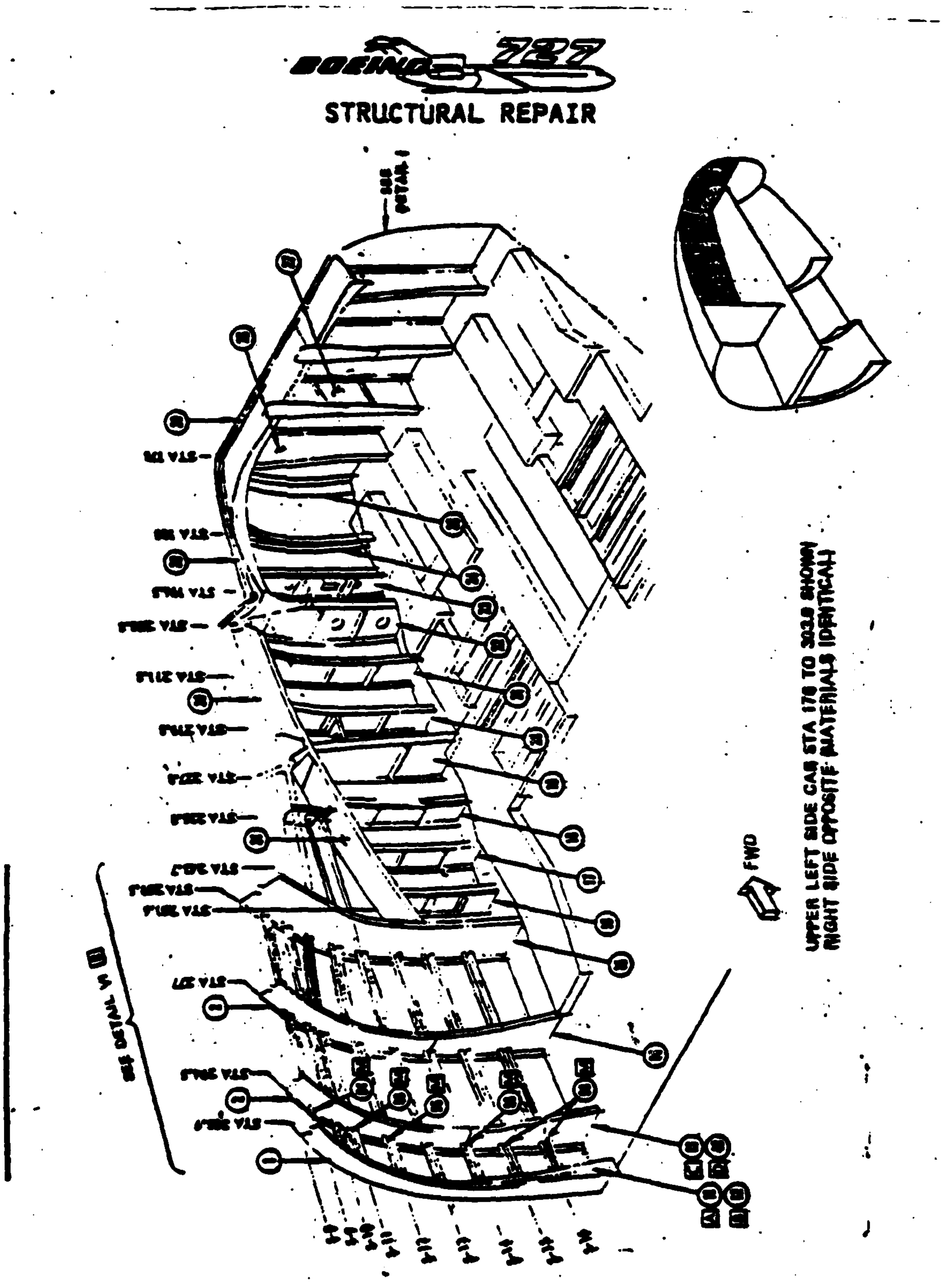


FIGURE E-8. SECTION 41 STRUCTURE IDENTIFICATION

APPENDIX F

HUD CHECKLISTS

1. <u>Power On</u>

Aircraft Power - Check that 115V, 400 cycle AC and 28V DC power are available. <u>Caution</u>: The DEU has a cooling fan installed which must be powered or the DEU could overheat causing damage to internal circuitry.

HUD Acrylic Block - Flight Position (Unstowed)

HUD Brightness Control (DEU) - Full Down (Counterclockwise)

HUD Video Switch (DEU) - Test

HUD Power Switch (DEU) - On

HUD Power Switch (PMCP) - On

HUD Push to Test Switch (PMCP) - Press to test all lights and indicators

HUD PMCP Brightness - As Desired

HUD "TEST COND" Switch (PMCP) - As Desired

HUD Brightness Control (DEU) - As Desired. <u>Caution</u>: Allow a sufficient warmup time after turning the HUD power on (approximately 20 to 30 seconds) before turning the brightness up. If brightness is at a high setting before the CRT illuminates, damage to the tube could occur.

HUD Video Switch (DEU) - Normal

2. <u>Before Takeoff</u>

"A REF" - Set for Departure

"REF" - Set for Departure

"IAS" - Set for Departure

"GS" - Set (0 or wind shear avoidance value)

Flight Mode - "TO/GA"

"B/R ALT" - Set (Normally 0 for departure)

"BARO" - Selected if desired

"CRS/HDG" - Set for Departure

Gamma Slew - Select "HDG" or "CRS" if not using INS computations

Guidance - As Required

"TEST" - Perform and verify agreement between rotating cross hair and HUD boresight

"TEST COND" - Selected if desired

HUD Brightness (DEU) - Set for Departure

PMCP Brightness (PMCP) - Set for Departure

Acrylic Block (PDU) - Check fully in flight detents. Warning: The HUD acrylic block must be checked in both lateral and longitudinal flight detents by physically pushing the acrylic block to the left and then toward the pilot. Failure to observe this precaution could result in erroneous pitch attitude relative to the outside visual scene.

Test Conductor before Takeoff Check - "Complete"

3. Descent/Approach

HUD Acrylic Block - Unstowed when desired

HUD Brightness Control (DEU) - Full Down (Counterclockwise)

HUD Video Switch (DEU) - Normal

HUD Power Switches (DEU & PMCP) - On. Caution: Check power available, otherwise, adequate cooling to the DEU may not be available.

HUD Brightness (DEU) - As desired after sufficient warmup period (20 to 30 seconds).

PMCP Brightness (PMCP) - Set for Arrival

"ALT REF" - Set for Approach

"REF" - Set for Approach

"IAS" - Set for Approach

"GS" - Set (0 or wind shear avoidance value)

Flight Mode - "IMC" or "VMC," as desired

"B/R A" - Set for Approach

"BARO" - Selected, if desired

"CRS/HDG" - Set for Approach

Gamma Slew - Select "HDG" or "CRS" if not using INS computations

Guidance - Selected for Approach

"TEST" - Perform and verify agreement between rotating cross-hair and HUD boresight.

Test Conductor Approach Check - "Complete"

4. Final Approach

HUD Acrylic Block - Check firmly in flight detents. Warning: The HUD acrylic block must be checked in both lateral and longitudinal flight detents by physically pushing the acrylic block to the left and then toward the pilot. Failure to observe this precaution could result in erroneous pitch attitude relative to the outside visual scene.

5. Missed Approach

Flight Mode - "TO/GA"

"IAS" - Enter

"ALT REF" - Set for Missed Approach

"GS" - Set for Missed Approach

"CRS/HDG" - Set for Missed Approach

Guidance - As Required

6. After Landing

HUD Brightness Control (DEU) - Full Counterclockwise

HUD Acrylic Block - Stowed

7. Power Down

"TEST COND" Switch (PMCP) - Off

HUD Power Switch (PMCP) - Off

HUD Power Switch (DEU) - Off

APPENDIX G

CHARTS OF FLIGHT PROFILES

Chart	Location
1. HUD operating routes	San Francisco Local Area
2. HUD departure and arrival routes	San Francisco Bay Area
3. Radar/PAR	Moffett Field NAS
4. Southland Six departure	Moffett Field NAS
5. TACAN Runway 35 approach	Crows Landing NALF
6. HUD approach traffic patterns	Crows Landing NALF
7. ILS Runway 29R	Stockton, CA
8. HUD approach traffic pattern	Stockton, CA
9. ILS Runway 21L CAT II	Travis AFB

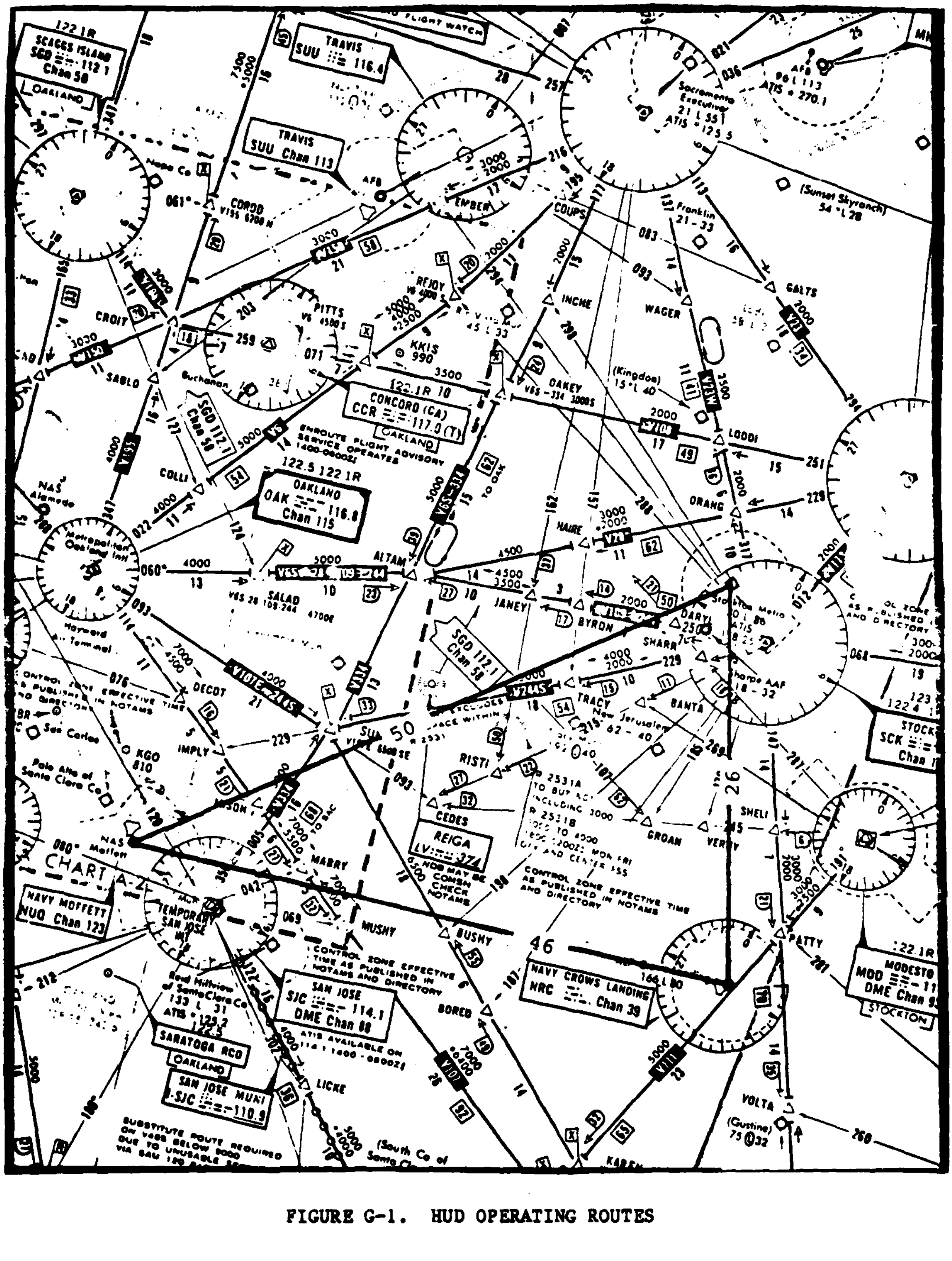


FIGURE G-1. HUD OPERATING ROUTES

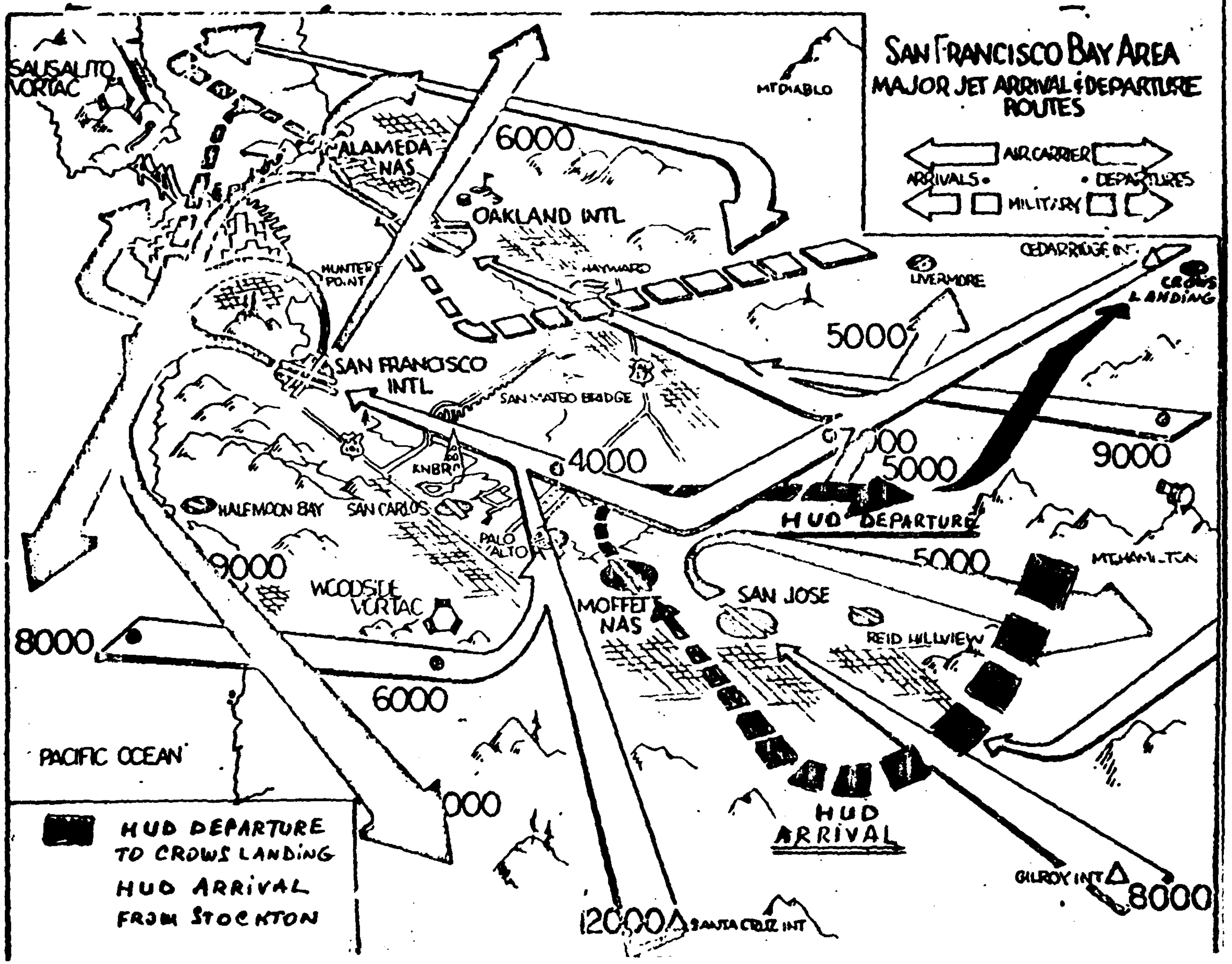
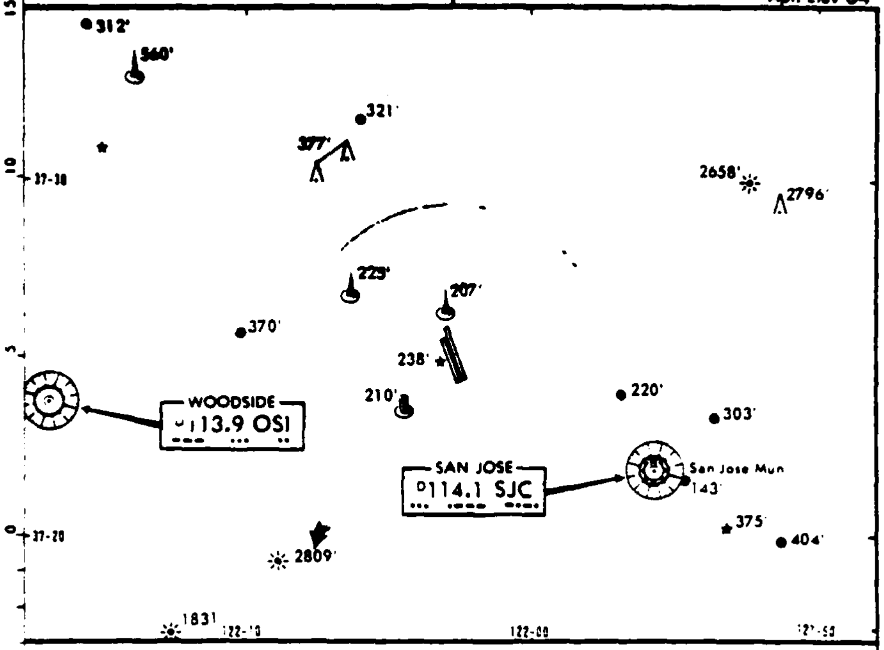


FIGURE G-2. HUD DEPARTURE TO CROWS LANDING AND HUD ARRIVAL FROM STOCKTON

Jeppesen Approach Chart SEP 22-78 (32-1)

MOFFETT FIELD NAS
MOUNTAIN VIEW, CALIF.
RADAR
PAR All Rwys
ASR All Rwys
Apt. Elev 34'

BAY Approach (R) 120.1
NAVY MOFFETT Tower 126.2
Ground 121.85



MISSED APPROACH: As directed by RADAR CONTROLLER.

TDZE RWY 14L 3' TDZE RWY 14R 11 TDZE RWY 32L 34 TDZE RWY 32R 29

STRAIGHT-IN LANDING

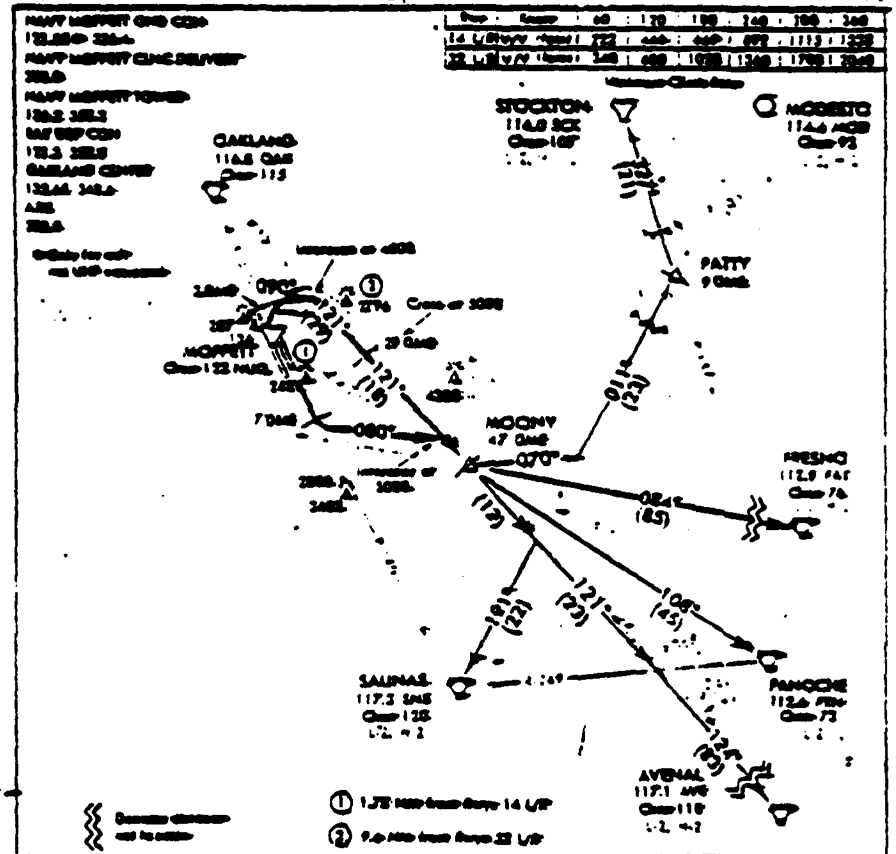
	PAR 14L DH 203'(200')	PAR 14R DH 211'(200')	PAR 32L DH 234'(200')	PAR 32R DH 229'(200')	ALS out
A B C D	3/4	3/4	3/4	RVR 24 or 1/2	RVR 40 or 3/4

	STRAIGHT-IN LANDING				CIRCLE-TO-LAND
	ASR 14L MDA 460'(457')	ASR 14R MDA 460'(449')	ASR 32L MDA 500'(466')	ASR 32R MDA 500'(471')	MDA
A B	1	1	1	RVR 50 or 1	540'(506')-1
C	1 1/4	1 1/4	1 1/4	RVR 60 or 1 1/4	560'(526')-1 1/2
D	1 3/4	1 3/4	1 3/4	1 3/4	600'(566')-2

CHANGES: ASR visibilities.

FIGURE G-3. MOFFETT FIELD NAS RADAR/PAR

SOUTHLAND SIX DEPARTURE(SOLN6•MOO 'Y) MOFFETT FIELD NAS



DEPARTURE ROUTE DESCRIPTION

Take-off Runways 32L/R: Complete right turn to 090° within 3 NM of NUQ to intercept and proceed via OAK R-121 to MOONY INT. Intercept OAK R-121 at 4000. Cross the 29 DME at 5000.

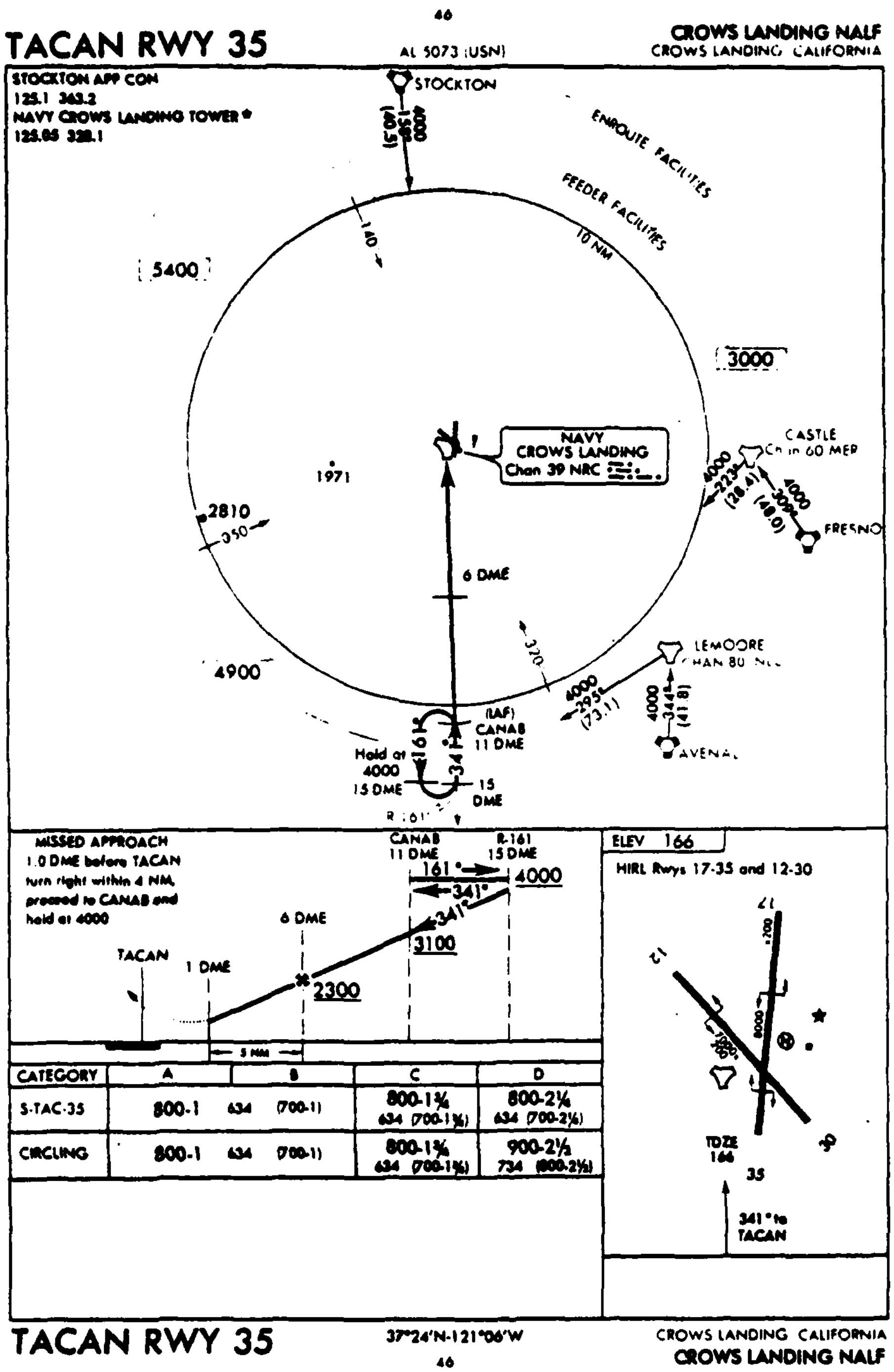
NOTE: A minimum continuous climb rate of 496 feet per mile is required to intercept OAK R-121 at 4000. Aircraft unable to meet this standard may request radar vectors

Take-off Runways 14L/R: Climb via NUQ R-140 to the 7 DME, then turn left heading 080° to intercept and proceed via OAK R-121 to MOONY INT. Intercept OAK R-121 at 5000.

(Continued on next page)

SOUTHLAND SIX DEPARTURE(SOLN6•MOONY) MOFFETT FIELD NAS

FIGURE G-4. MOFFETT FIELD NAS SOUTHLAND SIX DEPARTURES



CATEGORY	A	B	C	D
S-TAC-35	800-1 634 (700-1)		800-1¾ 634 (700-1¾)	800-2¼ 634 (700-2¼)
CIRCLING	800-1 634 (700-1)		800-1¾ 634 (700-1¾)	900-2½ 734 (800-2½)

FIGURE G-5. CROWS LANDING NALF TACAN, RUNWAY 35 APPROACH

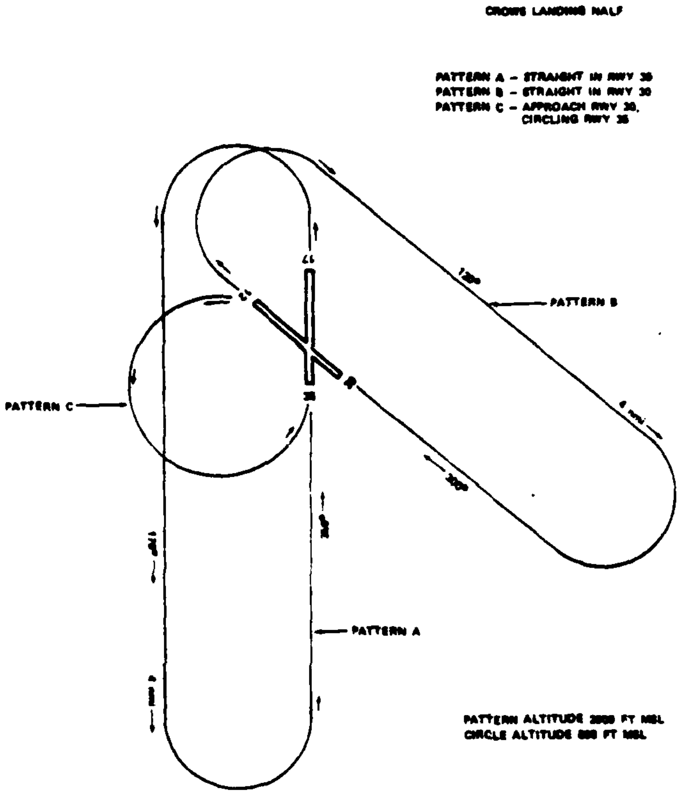


FIGURE G-6. HUD CROWS LANDING APPROACH TRAFFIC PATTERNS

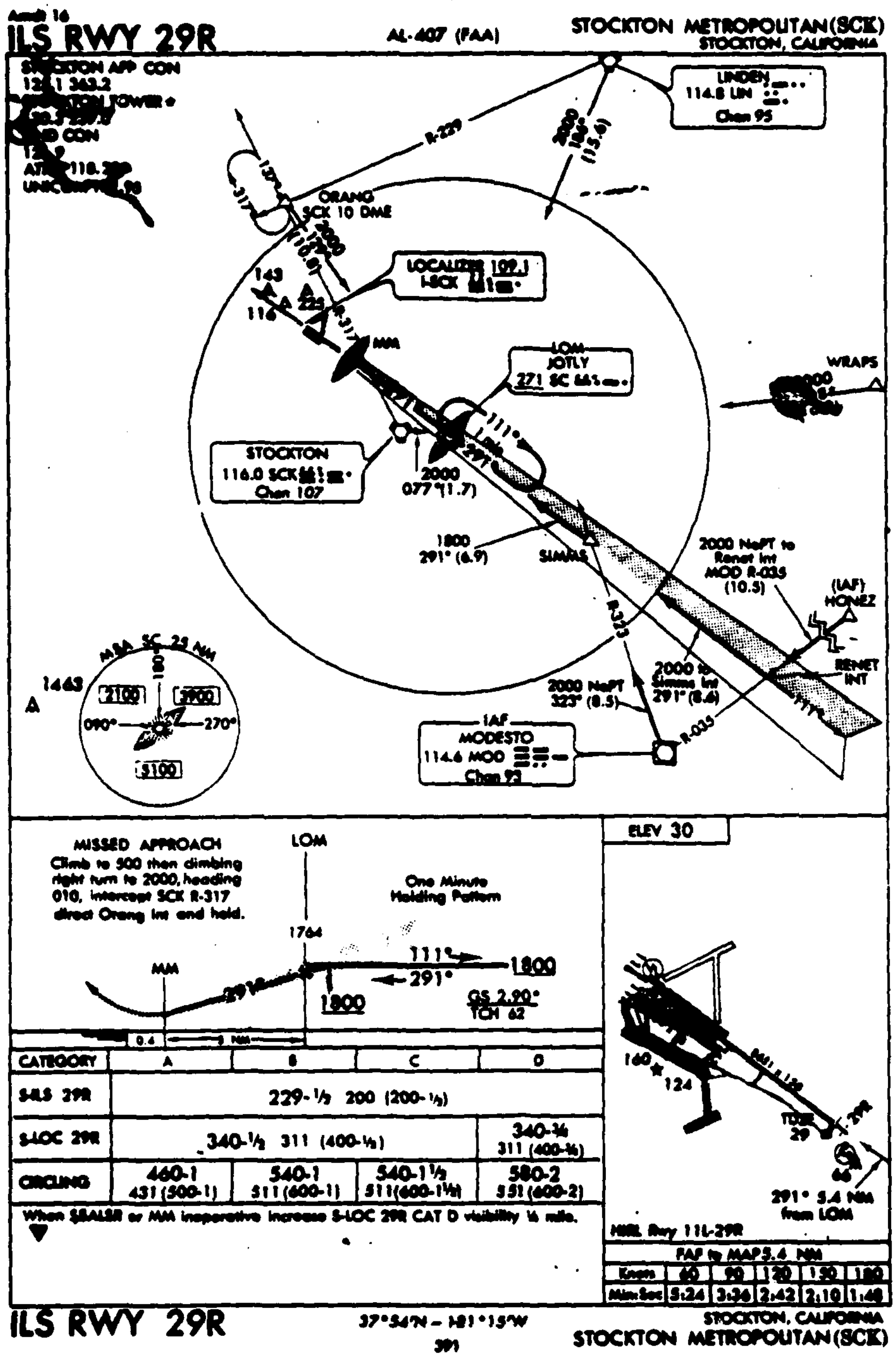


FIGURE G-7. STOCKTON, CA ILS RUNWAY 29R

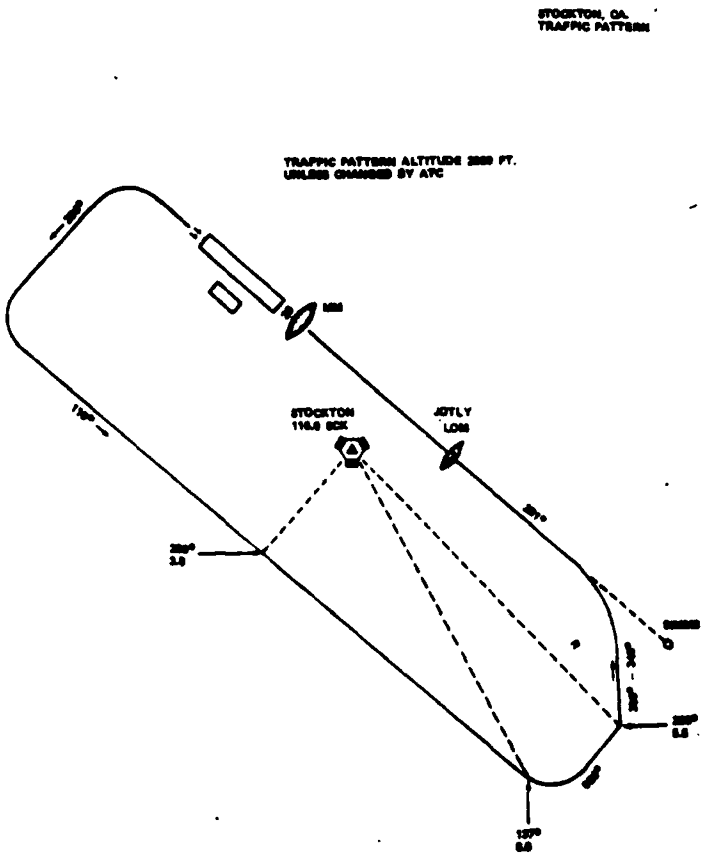


FIGURE G-8. HUD STOCKTON APPROACH TRAFFIC PATTERNS

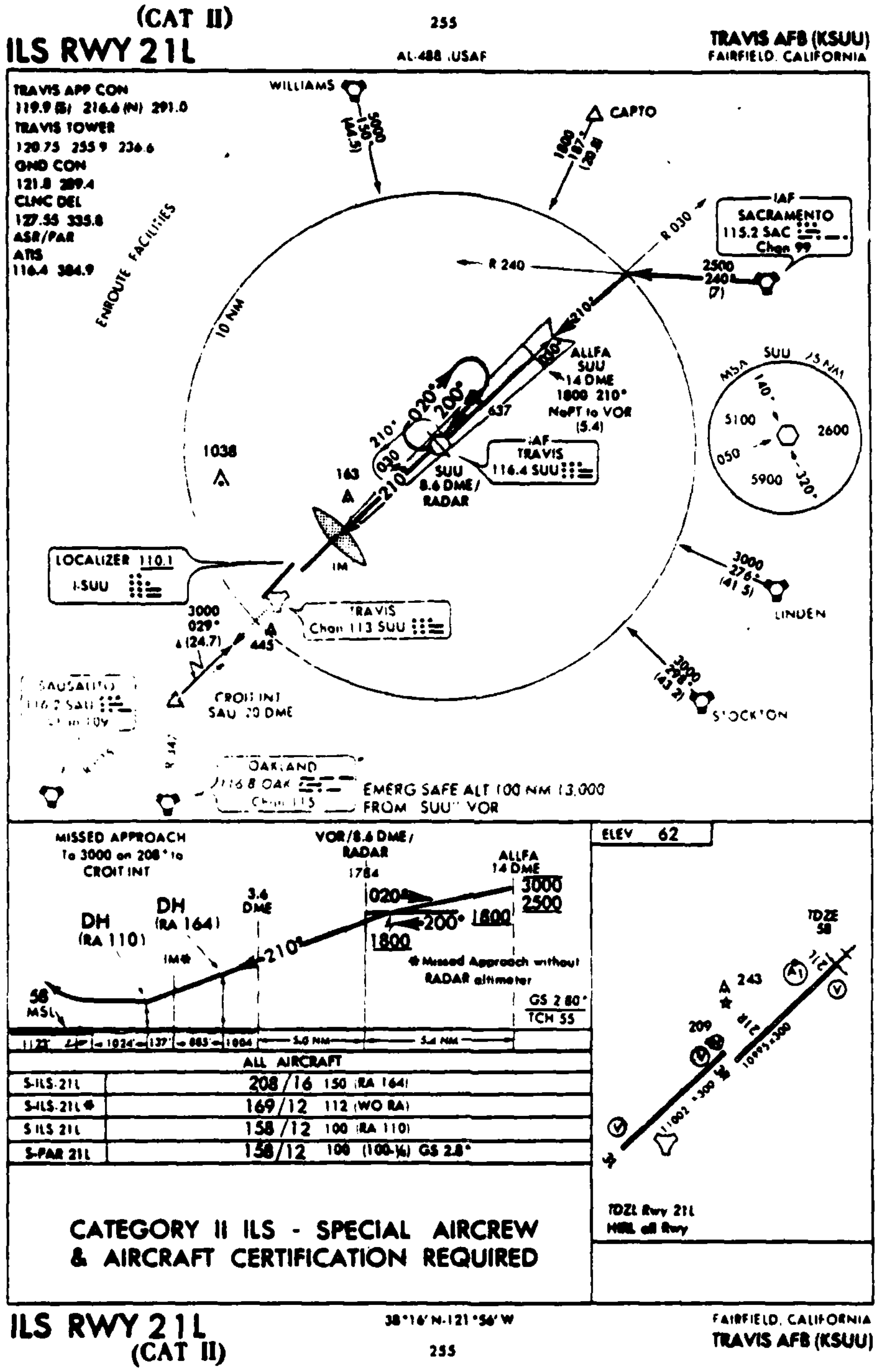


FIGURE G-9. TRAVIS AFB ILS RUNWAY 21L CAT II

APPENDIX H

HUD QUESTIONNAIRES

GENERAL

Subject: Date:

It is the purpose of these flight tests to obtain your perceptions of the possible advantages and disadvantages of the head-up display concept as experienced within the constraints of this flight program. In answering the following questions, please keep in mind that the primary objectives of the development of head-up displays for transport aircraft are the following:

1. To assist in the transition from IMC to VMC in low visibility ILS approaches.

2. In the absence of ILS glide slope information, to provide flightpath guidance in the visual segment of the approach.

The designer of this display has assumed that it is necessary for the pilot to be using the display, with essentially no dependence on instrument panel displays, prior to the final VMC portion of the approach. Thus, an important additional objective of the head-up display development is to provide attitude, guidance, and speed information in the form that is at least as effective in the final approach as the panel displays to which you are accustomed. While it is recognized that the application of a "see-through" display to this segment of flight can be questioned, there exists the objective of evaluating the novel display format, in comparison to the conventional panel displays, in these important maneuvers.

In view of the above objectives, the questions that follow are grouped by approach segment.

1. Terminal Area Maneuvering - The first group of questions addresses the adequacy of the display, as presented, for general terminal area maneuvering.

2. Approach-IMC - The second group of questions will address your assessment of the display (your observations regarding advantages and disadvantages relative to conventional panel displays) in the IMC portion of the final approach, beginning with OM passage.

3. Approach-Visual Segment - The third set of questions addresses the effectiveness of the display in the IMC-VMC transition, the visual segment of the final approach, and the landing itself. These questions pertain to the primary objectives of head-up display development.

In the answers to many of the following questions, it is appropriate to start with a comparative statement ("very much worse," "worse," "the same," "better," "very much better") and follow with a brief explanation.

I. <u>Terminal Area Maneuvering (Prior to Approach Fix)</u>

1. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to:

   a. Attitude
   b. Heading
   c. Speed Control
   d. Altitude Control
   e. Position and Path Relative to ILS Localizer

2. List any advantages or disadvantages of the display in regard to:

   a. Localizer Capture
   b. Aircraft Reconfiguring (Flap and Gear Extension, Deceleration)

II. <u>Approach - IMC</u>

A. ILS Approach

1. A comparison with conventional panel instruments, comment on the effectiveness of the head-up display, in terms of ease and precision of control, in the tasks of:

   a. Maintaining Position on Glidepath
   b. Maintaining Position on Localizer Course
   c. Speed Control

2. Again, in comparison with panel instruments, comment on the effectiveness of the display in providing the following status information:

   a. Attitude
   b. Rate-of-Descent
   c. Displacement from ILS Path
   d. "Time-to-Go"
   e. Pitch and Roll Attitude
   f. Drift (or Crab) Angle
   g. Location of the Runway

3. Is there superfluous information in the display?

4. Are there additional items of information that you would like to see in the display in this flight segment?

B. Localizer Only - Front Course

1. In comparison with your conventional procedures, comment on the effectiveness of head-up display in the management of flightpath from the approach fix to establishment at MDA. Address particularly:

a. Provisions for Rate-of-Descent Control
b. Altitude Awareness
c. MDA Capture and Hold
d. Localizer Guidance

III. Approach - Visual Segment

A. Visual Segment of ILS Approach

1. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to:

   a. Evaluation of Visibility Conditions during IMC-VMC Transition
   b. Decision Height Annunciation
   c. Awareness of Runway Location
   d. Ability to maintain Desired Flightpath and Speed to Flare Altitude:

      (1) In nominal conditions
      (2) In shears

   e. Coping with Crosswinds

2. Prior to flare altitude, does use of the head-up display deprive you of information that is normally available on the panel or in the visual scene?

3. Prior to flare altitude, to what extent do you assess the "outside" view of the runway relative to your attention to the displayed information?

4. If you utilized the "declutter" option, under what circumstances and at what point in the approach was it used?

5. What is your evaluation of the declutter option?

6. To what extent do you utilize the "flare line" (or ground proximity indication) to initiate the landing flare?

7. Do you experience any conflict or dilution of normal cues when utilizing the flare line for either flare initiation or for control of trajectory to touchdown?

8. Does use of the flare-line interfere with lateral-directional control in the flare?

9. Please add any additional observations you might have regarding the adequacy of the head-up display in the final ILS approach and landing.

10. Did you use the head-up display in the go-around maneuver? If so, did it present any special advantages or difficulties?

11. Would greater familiarity with the go-around use of the display have been helpful?

B. Visual Segment of Localizer-Only Approach

1. In comparison with conventional systems, comment on the contributions or problems introduced by the head-up display in regard to:

    a. Evaluation of visibility conditions while maintaining desired flight conditions.
    b. Determination of the initiation of descent from MDA (use of the "-3° dots" to evaluate position relative to 3 degree glide path).
    c. Maintenance of desired flightpath and speed to flare in: (1) Nominal conditions; and (2) turbulence or shears.

2. Please add any additional observations you might have regarding the display in the localizer-only approach.

AIRMASS VERSUS INERTIAL

Now that your flight experience has been completed and presumably you have obtained a more in-depth understanding of HUD performance in its various modes of operation, completion of this questionnaire will provide subjective information relative to your assessment of the merits of the airmass mode and inertial mode as implemented in this particular HUD.

In the answers to many of the following questions, it is appropriate to start with a comparative statement ("very much worse," "worse," "the same," "better," "very much better") and follow with a brief explanation.

1. Please comment on the two modes in relation to:
    a. Performance in crosswinds
    b. Performance in gusty vertical wind shear conditions
    c. Performance of the flightpath symbol in acquiring and maintaining localizer centerline
    d. Presentation and interpretation of required drift corrections
    e. Accuracy of presented drift corrections
    f. Vertical response of the flightpath symbol during climb, turns/banks, and level flight
    g. Ease of interpretation and usage

2. Compare the extent to which the airmass and the inertial mode HUD aided you in executing approaches to minimums.

3. With which mode did you feel most confident when executing low approaches? Why?

4. Which mode do you prefer? Why?

FINAL

Subject: Date:

Now that you have completed all the flight work and had several more simulator sessions, we would like to get some additional comments. First, please review your answers to sections I, II, and III in light of your additional flight experience and list here any significant changes you might make to those answers. Use the attached blank questionnaire for this purpose.

In addition to your review of the initial questionnaire, we need to get your views on any findings that are unique to the flight portion of this program and specifically to the fact that you were using actual flight hardware in the real world environment. Please answer the following questions:

1. Did you have any problems with the physical location of the Pilot Display Unit (e.g., interference with forward view, closeness, uncomfortable seat position, etc.)?

2. Please comment on the visual quality of the head-up display (e.g., brightness, distortion, clarity, jitter, etc.).

3. Did you experience any eye discomfort?

4. Did you notice any tendency to fixate on any elements of the display to the exclusion of other elements or the real-world scene?

5. Were you able to take your attention away from the display and return it comfortably?

6. Did you notice any tendency for the display symbology to mask or obscure necessary outside cues such as approach lights, runway lights, markings, or other aircraft for collision avoidance?

7. Please list any questions you might have regarding the usefulness of this head-up display that have not been addressed in this program.

Finally, we need to address two very important objectives of this whole program. First, we need to obtain a direct assessment of the transfer of HUD training from simulation to flight. Second, we need to qualitatively assess the degree of validity we can apply to the simulation results to date based on the experience you just had with both simulation and flight.

We will use a tape recorder for these comments.

APPENDIX I

PILOTS RESPONSES TO HUD QUESTIONNAIRES

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)

QUESTION: I.1.a. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to attitude.

Subject	Remarks
1	Same - surprisingly the bank angle is easy to determine.
2	Same - except in a bank. Little to no awareness of bank without looking at ADI.
3	Very much better - cuts down scan requirements.
4	Better - due to both the outside world and precise HUD attitude information.
5	Less aware of pitch than ADI due to location of pitch symbol. Less aware of roll angle but more aware of turning condition.
6	Better - with possible exception of bank angle due to lack of a specific reference.
7	Much better - Flightpath and horizon provide more accurate altitude hold capability without scanning several instruments. Altitude capture bars good approaching altitude but confusing holding altitude.
8	Worse - Roll attitude not shown. Tendency to ignore pitch while concentrating on flightpath.
9	Head down, attitude is determined by placing aircraft symbol on the ADI. Using HUD, it appears that pitch attitude is a fallout of controlling flightpath. Under almost all conditions, the HUD is better in that flightpath is what must be controlled and not pitch attitude. Hopefully, there won't be a time where controlling flightpath could result in an aircraft pitch attitude that cannot be sustained without pilot awareness.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)

QUESTION: I.1.b. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to heading.

Subject	Remarks
1	Better for small heading changes (10^{o}). Worse for large changes. Without compass rose symbology, more interpretation required.
2	Very much better - slightly more difficult to roll out precisely on desired heading.
3	Very much better - cuts down scan requirements.
4	Better feel for actual heading since it is included in the HUD. Worse for knowing what desired heading should be.
5	Better
6	Same - better for maintaining specified heading, worse for lead-in information when turning.
7	Worse - lack of compass rose for large turns and lack of heading reference bug creates large mental workload. Had difficulty seeing heading reference without moving head. Had trouble holding precise headings. Tend to make many small inputs around set heading.
8	Worse - no equivalent of heading bug to remind of target heading/
9	In INS mode, flying course seems better than head down where control of heading results in a course dependent on winds. If flying heading is required, head down is better. HUD requires control of attitude using gamma and heading using pitch symbol. Symbols being split makes for high workload. One to one sensitivity in HUD makes high workload in precise heading control.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)

QUESTION: I.1.c. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to speed control.

Subject	Remarks
1	Very accurate but tends to make pilot chase speed in turbulence, etc.
2	Very much better - digital readout easy to scan. Potential gamma is tremendous indicator for trend. Speed worm good but not of great importance.
3	Very much better - cuts down scan requirements.
4	Better
5	Better - due to location of airspeed, fast/slow, and potential gamma.
6	Very much better when airspeed error used with potential gamma.
7	Better - digital readout good. Very much in scan. Airspeed worm glows too much. Too large for small errors.
8	Better - built-in "speed bug" assuming pilot could easily set desired speed.
9	Same - digital readout plus speed error can provide precise speed control but at expense of high workload. Workload would decrease considerably with experience.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)

QUESTION: I.1.d. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to altitude control.

Subject	Remarks
1	Very much better using potential flightpath symbol.
2	Very much better - digital readout and command line of great help. Tendency to go after 10 - 20 feet changes, more than if using standard altimeter.
3	Very much better - excellent during straight and level or small straight ahead changes. Tended to miss altitude command during high rate changes in altitude or heading.
4	Same - flightpath information is much better but a director is easier to see than the HUD altitude reference. It gets lost in the clutter of horizon and pitch scale lines.
5	Much better - when attention is given to altitude error symbol but symbol should be changed or enhanced to be more conspicuous.
6	Better except for error that occurs during bank.
7	Better - altitude readout close to flightpath good. Altitude capture bars good approaching altitude, once you're aware of them. Missed them on 2 occasions due to concentration of other things. Confusing once captured as bars displace too much for small altitude excursions.
8	Better for holding altitude using flightpath on horizon. Worse for climb/descent - no vertical speed and no target altitude until close to altitude.
9	Better - placing the flightpath symbol on the horizon is a single action that solves the problem. Altitude reference lines provide a simple means to determine the lead or rate of change to attain a desired altitude. Also provides a good altitude reminder system.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)

QUESTION: I.l.e. In comparison with conventional panel instruments, comment on the adequacy of the head-up display prior to final approach, in providing general situation awareness in regard to: postion and path relative to ILS localizer.

Subject	Remarks
1	Same - easier to track, more difficult to capture.
2	Worse - more difficult to pick up course intercept line and track it to localizer. Gain on course intercept line should be greater than the 4 to 1. After interecpt is completed, localizer following on HUD is better than head down.
3	Worse - takes mental effort to determine situation display. Localizer capture command too subtle. Missed it on most runs. OK after capture.
4	Very poor.
5	Localizer intercept and position sensing not as obvious as head down. Potential for confusion does exist. Conceptual training required.
6	Worse - display can be confusing.
7	Much worse - takes too much mental workload to picture intercept. Runway centerline symbol along with localizer capture bar and ILS dot too much. Didn't have an accurate picture in my mind of position relative to ILS. Had to refer to ADF to appreciate picture relative to OM on intercept.
8	Worse - difficult to interpret display for relative position and rate of closure to localizer.
9	Same on glideslope. Unacceptable on localizer. If raw data was presented properly, position relative to localizer would be the same as head down. Difficult to comprehend display indicating aircraft left or right of runway and the gamma symbol seemingly on the wrong side of the course symbol to make an intercept.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Terminal Area Maneuvering (Prior to approach fix)
QUESTION: I.2.a. List any advantages or disadvantages of the display in regard to localizer capture.

Subject	Remarks
1	More difficult in capture mode. Localizer symbol comes off parked position and if you don't turn immediately you usually don't catch it.
2	Disadvantage is capture rate. Recommend gain greater than 4:1.
3	Too subtle to catch from intercept heading.
4	Quite hard to capture on the HUD, usually overshot. HSI with RMI is much better.
5	Not as comfortable or obvious as head down. Suggest removal of symbol until within 2.5°, then flash symbol, then on steady, and then moving in direction for intercept.
6	Lead-in cues occur with too short of a warning causing overshoots and abrupt control inputs.
7	With HUD, could not get picture of where I was in relation to localizer without great mental workload. Runway symbol, localizer, and glideslope symbol all coming together was confusing.
8	Localizer deviation indicator initially on wrong side. Some tendency to confuse. HSI plan view with HUD vertical view of localizer symbol.
9	Head down provides closure on the desired ILS localizer and provides cues for when the localizer will come alive.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : **Terminal Area Maneuvering** (Prior to approach fix)

QUESTION: I.2.b List any advantages or disadvantages of the display in regard to aircraft reconfiguring (flap and gear extension, decelerating)

Subject	Remarks
1	Much better using potential flightpath and flightpath.
2	Slightly easier because of airspeed display and body angle indication with flap schedule change.
3	Much better - when aim airspeed has been inserted. Potential flightpath symbol excellent.
4	Flightpath and potential flightpath are very good information. You can tell at a glance if you are going to make it (e.g., go-around or decelerate to threshold).
5	Acceleration cues with fast/slow and potential flightpath were advantageous.
6	With flightpath and potential flightpath, aircraft can be flown through this regime more smoothly and precise (safer).
7	No advantage - airspeed error worm, although good tool, lost its effectiveness during reconfiguring and deceleration. Purposely slowing down gave large speed worm error which you soon ignore or also gave you concern.
8	No problem in HUD- assuming pilot/copilot have convenient way to program HUD desired speed.
9	Advantage is the capability to easily maintain level flight during speed changes.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.1.a. In comparison with conventional panel instruments, comment on the effectiveness of the head-up display, in terms of ease and precision of control, in the tasks of maintaining position on localizer course.

Subject	Remarks
1	Very easy in INS mode. Difficult with crosswind in the airmass mode.
2	Better to fly a more precise localizer, however, could cause a tendency to overcontrol to follow the conformal symbology display. Have to think about not going after the symbols.
3	Much better - less effort through less scan. Good resolution.
4	I had a tendency to S-turn with INS data - probably a little worse than with a good flight director With airmass, I didn't S-turn but the picture was a little hard to figure out.
5	Localizer sensitivity and display added to workload. However, with greater effort applied, localizer accuracy was greater with the HUD.
6	Better - handles drift angle corrections better. Takes any guesswork out of heading selection.
7	High workload trying to keep flightpath symbol around loc/GS circle. Not aware of anything but airspeed. Did not see DME, DH and unaware of aircraft postion on ILS as with head down.
8	Easier than raw data but not as good as a flight director due to smaller symbols. Generally poorer display.
9	HUD provides for increased precision in flying ILS approach. Because increased precision requires more course changes and corrections, it increases workload. HUD is less work.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.1.b. In comparison with conventional panel instruments, comment on the effectiveness of head-up display, in terms of ease and precision of control, in the tasks of maintaining position on glidepath.

Subject	Remarks
1	Very easy both modes.
2	Very much better - INS.
3	Same
4	Very easy with INS mode (nice integration of situation and director information) but poor presentation with airmass data (system performance was good, however.)
5	Better once established but not as good for the initial capture. The means to maintain glidepath still caused greater workload.
6	Very much better - using the "ghost airplane" technique eliminates th need for a busy scan pattern. This display centers all pertinent info.
7	Workload was so high flying flightpath did not notice 3^{o} depression line. Runway symbology too prominent.
8	Easier than raw data but not as good as a flight director - due to much smaller symbols - generally poorer display.
9	Precision better on HUD, less work.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach

QUESTION: II.A.1.c. In comparison with conventional panel instruments, comment on the effectiveness of the head-up display, in terms of ease and precision of control, in the tasks of speed control.

Subject	Remarks
1	Easy but tendency to work too hard. Tend to correct for one knot speed changes.
2	Very much better.
3	Same.
4	Better because the speed information is always in your scan.
5	Much better.
6	Very much better - speed error and potential flightpath are excellent for minimizing throttle movement while providing excellent precision with wind shear detection available.
7	Better - due to location of digital readout next to flightpath. Speed error worm tended to be too large which is distracting.
8	Better.
9	Same.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.a. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information : attitude.

Subject	Remarks
1	Excellent.
2	Same - except in bank - little awareness of bank without looking at ADI.
3	Better - should improve bank angle cue. Simulator flightpath symbol is better.
4	Same - good.
5	Pitch and roll awareness less than head down. HUD attitude awareness considered satisfactory.
6	Better for pitch attitude and longitudinal flightpath tracking. Same or worse for bank angle and/or lateral tasks.
7	So engrossed with flightpath symbol, was not aware of aircraft symbol.
8	Essentially same comment as terminal area but attitude not as critical on final approach as during maneuvering.
9	Better - in reference to pitch and bank.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach

QUESTION: II.A.2.b. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information: rate-of-descent.

Subject	Remarks
1	Easy on ILS glideslope.
2	Same - rate-of-descent is only available via flightpath symbol and fixed depression lines. If fpm is needed, you can always look down.
3	Don't need it with potential flightpath symbol.
4	Much better - flightpath is what a pilot needs and it is integrated into primary altitude display.
5	Actual flightpath should be an adequate substitute once some limits are established.
6	Worse in terms of actual feet per minute but better in terms of actual flightpath of aircraft.
7	Had no appreciation of rate-of-descent on localizer with HUD- created apprehension.
8	Much worse - no vertical speed on HUD.
9	No vertical speed guidance. NPA's require 1000 fpm from FAF to MDA. Head down better here.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.c. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information: displacement from ILS path.

Subject	Remarks
1	Easy in INS - can be difficult in airmass.
2	Same or better in INS, worse or much worse in airmass.
3	Very much better.
4	Worse - Qualitatively it is good as long as the picture is interpretable.
5	Overall not as obvious or intuitive as head down.
6	Better - although this display tends to exaggerate displacements.
7	Felt that cues were not as good as head down - tended to concentrate on ILS dot.
8	Better - no need to shift eyes from ADI to HSI.
9	HUD shows displacement from path with greater accuracy. Maneuvering to correct the path results in higher workload because of many minute displacements requiring corrective action.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.d. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information: "time-to-go"

Subject	Remarks
1	Easy because of the visual concept.
2	Same - only indication of time to go to touchdown is altitude readout.
3	No comment.
4	Same - growing runway helps but must use the altitude display which is nicely integrated into primary display.
5	Better in HUD with inertial.
6	Better - DME display plus absolute altitude are useful.
7	Completely missed DME readout during approaches. Target fixation with flightpath and ILS circle.
8	Same
9	Head down is better since HUD does not provide a clock display. Copilot could fill this role.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.e. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information: pitch and roll attitude.

Subject	Remarks
1	Pitch easier. Roll same of slightly more difficult.
2	Pitch much better. Roll worse.
3	Pitch better. Roll - need better index.
4	Same - good.
5	Not as obvious.
6	Pitch - better. Roll - worse.
7	No comment
8	Worse - pitch symbol very small. No roll attitude shown in HUD.
9	ADI provides better pitch and roll indications. Use of flightpath and accepting resulting pitch is acceptable but bank angle info should be in HUD.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.f. In comparison with panel instruments, comment on the effectiveness of the display in providing the following status information: drift or crab angle.

Subject	Remarks
1	Easier using potential flightpath.
2	Very much better in INS mode.
3	Very much better.
4	Same - HUD is good but so is HSI.
5	Obvious when in "heading slew" but not course slew.
6	Better.
7	Workload too high to appreciate.
8	Better.
9	If the aircraft is tracking a known course, then HUD and head down are the same. In the INS mode, HUD had obvious advantage of showing crab angle even when flying only headings.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.2.g. In comparison with panel instruments, comment on the effectiveness of the display in provididng the following status information: Location of the runway.

Subject	Remarks
1	Much easier with runway symbol, however, the runway symbol should be shorter.
2	Artificial runway symbol makes it better than with raw data.
3	Confusing on intercept. Very much better on final approach.
4	Much better. Gives a good feel for where the runway is. With head down, a pilot must generate this "feel" himself.
5	HUD slight improvement with runway symbol.
6	Very much better.
7	Not sure at this time.
8	Much better.
9	Better. In my opinion, the HUD should not display the runway much above 200 feet AGL because of clutter.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach
QUESTION: II.A.3. Is there superfluous information in the display?

Subject	Remarks
1	No.
2	No.
3	No.
4	No.
5	The runway symbol.
6	No.
7	Declutter on flare should be automatic. Get rid of unnecessary cues during flare. Speed worm should disappear. Keep it simple.
8	No.
9	No.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - ILS Approach

QUESTION: II.A.4. Are there additional items of information that you would like to see in the display in this flight segment?

Subject	Remarks
1	Possibly vertical velocity to aid in leveling off.
2	A means to determine bank angle.
3	I think we could consider a max thrust alert so we don't blow our engines unless necessary. No EPR numbers but could be based on EPR settings.
4	Quantitative ILS deviation.
5	A 75 ua "CAT II box" positioned relative to the flightpath symbol.
6	OM and MM are very easy to miss. Frequency and duration are too low.
7	Vertical speed.
8	Vertical speed. Target landing, altitude and airspeed.
9	Vertical speed and bank angle information.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Localizer only

QUESTION: II.B.1.a. In comparison with your conventional procedures, comment on the effectiveness of head-up display in the management of flightpath from the FAF to MDA. Address particularly: provisions for rate-of-descent control.

Subject	Remarks
1	Very good because of projected glidepath. Unreliable in airmass mode.
2	Utilizing 5° depression line is excellent means of controlling descent to MDA.
3	OK with potential flightpath symbol and fixed depression angle.
4	Much better - 5° reference line very good. MDA reference line concept good but easy for me to miss.
5	Better - proper use of flightpath symbol will provide adequate and easier rate-of-descent control.
6	Very much better.
7	No comment.
8	Vertical speed needed in HUD.
9	None available - required when making non-precision approaches.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Localizer only

QUESTION: II.B.1.b. In comparison with your conventional procedures, comment on the effectiveness of head-up display in the management of flightpath from FAF to MDA. Address particularly altitude awareness.

Subject	Remarks
1	Excellent.
2	Very much better.
3	Better due to small scan.
4	Better - MDA reference and altitude integrated into display.
5	Adequate but can be improved by moving altitude closer to flightpath and reducing workload to allow more time for cross check. Overall, better.
6	Better - reference altitude bars are helpful for capturing altitudes.
7	No comment.
8	Satisfactory.
9	HUD is good because the altitude reference symbol cues you on MDA and assists in the level off.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Localizer only
QUESTION: II.B.1.c. In comparison with your conventional procedures, comment on the effectiveness of head-up display in the management of flightpath from the FAF to MDA. Address particularly MDA capture and hold.

Subject	Remarks
1	Didn't try this but I am sure it would be very easy because of ease of holding an altitude.
2	Very much better.
3	Same - altitude capture and hold symbol is OK for this since pilot is looking for it. Too subtle in some situations.
4	Better - a good flight director is maybe smoother but the display integration and status information helps.
5	Much better.
6	Better.
7	No comment.
8	Better than basic instrument. Worse than flight director.
9	Altitude reference symbol cues you and assists in level off.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Localizer only

QUESTION: II.B.1.d. In comparison with your conventional procedures, comment on the effectiveness of head-up display in the management of flightpath from FAF to MDA. Address particularly localizer guidance.

Subject	Remarks
1	Very easy because of flightpath symbol in INS. Airmass about the same.
2	Same - better to fly a more precise localizer course. Could, however, cause a tendency to over control to follow conformal symbology display.
3	Capture slightly worse.
4	Worse - concept good but I lost the picture once with both INS and airmass data. I think difference symbology might help.
5	No significant difference with INS. Airmass much worse.
6	Better.
7	No comment.
8	Better than raw data. Worse than flight director.
9	HUD more precise.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach

QUESTION: III.A.1.d. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to: *ability to maintain desired flightpath and speed to flare altitude in nominal conditio*

Subject	Remarks
1	INS -excellent. Airmass - much more difficult.
2	Very much better - due to availablity of gamma, potential gamma, and flare command law.
3	Better.
4	Much better - having airspeed and gamma in outside scan is excellent.
5	Generally easier to accomplish.
6	Very much better - pilot need never lose sight of these parameters.
7	Excellent.
8	No comment.
9	HUD provides greater precision throughout the approaches.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach

QUESTION: III.A.1.a. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to: evaluation of visibility conditions during IMC-VMC transition.

Subject	Remarks
1	Excellent - one of the greatest advantages of HUD.
2	Very much better - much easier to pick up real runway cues and ascertain visibility conditions.
3	No comment.
4	Should be much better but with clear conditions existing the question is academic.
5	HUD adds significantly in this regime.
6	Very much better - not actually observed in flight but through the simulator it would appear to be much improved.
7	No comment.
8	No comment.
9	HUD does contribute to the evaluation of visibility. It provides good guidance through questionable conditions until a final evaluation can be made and a landing or MA is completed.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.1.b. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to: decision height annunciation.

Subject	Remarks
1	No comment.
2	Same - would still require a "call out" as a reminder for DH. MDA seems better due to the level off bar.
3	No comment.
4	Same - head down rising runway is good. Less scan required for HUD though.
5	Inadequate - need positive annunciation rather than symbol removal.
6	Very much better - less chance to miss or mistake.
7	Completely missed DH on all visual and instrument approaches. Needs to be more prominent.
8	Not observed.
9	No comment.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach

QUESTION: III.A.1.c. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to : awareness of runway location.

Subject	Remarks
1	Excellent on final - somewhat confusing on downwind and base because of localizer symbol logic.
2	Better - due to artificial runway symbol.
3	Better - no focus problem.
4	Should be better but there were biases present in HUD. One half runway width in INS mode. One runway width and heading bias in airmass.
5	Use of HUD during transition aids in awareness of runway.
6	Very much better - symbolic runway.
7	Good.
8	Flare symbol of great value both IMC and VMC espcially as a "start flare" cue.
9	HUD runway symbol pictorially shows where the runway is and your relation to the runway at all times below 1000 feet AGL.

HUD QUESTIONNAIRE : GENERAL

SEGMENT :Approach - Visual Segment of ILS Approach
QUESTION:III.A.1.d. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to: ability to maintain desired flightpath and speed to flare altitude in shears.

Subject	Remarks
1	Simulator only - excellent for anticipating or early detection of shear. Allows power adjustment much earlier.
2	Very much better.
3	Better due to one to one response.
4	None experienced.
5	Not observed.
6	Very much better - potential gamma always available to pilot.
7	No comment.
8	Not observed.
9	No comment.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.1.e. In comparison with panel displays, comment on the contributions or problems offered by the head-up display in regard to: coping with cross-winds.

Subject	Remarks
1	Excellent with INS. Poor with airmass.
2	Same - INS. Very much worse in airmass mode.
3	Better in INS mode.
4	Same - with HUD biases I felt I wasn't using lateral information in visual segment.
5	HUD has potential to assist in cross-wind conditions.
6	Better - presents better picture of situation.
7	Good.
8	Not observed.
9	Because of split between gamma and heading indicator, the HUD is more difficult to fly. The HUD does assist in the decrab maneuver.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach

QUESTION: III.A.2. Prior to flare altitude, does use of the head-up display deprive you of information that is normally available on the panel or in the visual scene?

Subject	Remarks
1	No.
2	Feet per minute rate (compensated by fixed depression line).
3	No.
4	Not in conditions present but might in reduced visibilities. At night I felt the HUD may have obscured the outside scene slightly.
5	No.
6	No - except engine instruments.
7	No. As long as we have declutter mode.
8	HUD "instrument" obstructs pilots head when leaning forward to look out side windows to see runway traffic, etc. May inhibit good "clearance" practice.
9	Yes - vertical speed.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.3. Prior to flare altitude, to what extent do you assess the "outside" view of the runway relative to your attention to the displayed information?

Subject	Remarks
1	Very little at first - tended to fixate on the HUD. I had to learn to look through the HUD which was no problem.
2	I believe first approaches with HUD required a concentrated effort to look through the symbology to outside scene. After several approaches, however, it became natural.
3	About 25% HUD and 75% outside.
4	Because of the display biases, I tended to rely almost completely on the outside scene. Still tended to use gamma and speed information on the HUD though.
5	Outside is primary to assure lineup and aircraft tracking to land in touchdown zone. I will track HUD info as long as it agrees with the real world within nominal tolerances.
6	During VMC, higher use of outside information, using glideslope and airspeed checks every few seconds. Lineup almost exclusively outside.
7	With VMC symbology, completely aware of outside cues.
8	About equally.
9	80% assessment outside. This is up considerably because of experience with the HUD.

HUD QUESTIONNAIRE : GENERAL

SEGMENT :Approach - Visual Segment of ILS Approach
QUESTION:III.A.4. If you utilized the "de-clutter" , under what circumstances, and at what point in the approach was it used?

Subject	Remarks
1	Absolutely necessary to flare the aircraft in night operations. Runway lights were quite dim. De-cluttered at 50 - 100 feet.
2	Was not used.
3	Four times - just before flare bars cross flightpath symbol.
4	Didn't get a chance to evaluate
5	Did not use.
6	Necessary to use only at night.
7	Forgot - needs to be automatic at flare.
8	Not used deliberately.
9	Did not use.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.5. What is your evaluation of the declutter option?

Subject	Remarks
1	Necessary for night landings.
2	Did not use it.
3	Should be a requirement even though clutter didn't cause any particular problem to me.
4	Didn't get a chance to evalutate.
5	At any time HUD info is not required for the task it should be automatically removed, e.g. during approach digital heading is not required; below 50 ft. potential gamma and speed worm are not required. Pilots will generally forget to de-clutter.
6	Essential for night operations.
7	Should be automatic.
8	Did not find it of any value.
9	Like it but would use it close to ground and would like the following retained : gamma, depressed angle, speed, horizon.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.6. To what extent do you utilize the "flare line" (or ground proximity indication) to initiate the landing flare?

Subject	Remarks
1	Very little because I was usually looking through HUD by then.
2	To the greatest extent - especially because I am not rated in the 727, therefore, needed a crutch for flare and landing.
3	100% during manual landings.
4	Very little.
5	I used it rigorously. It is effective and a definite aid to the pilots.
6	Used to initiate flare consistently; however, it was found advantageous to complete the flare using real world cues.
7	Good but gets lost in clutter once it reaches flightpath symbol.
8	Used primarily to initiate flare. Completed flare and touchdown looking outside. Great value.
9	Almost entirely, if working at 50 feet; use it to landing attitude, then disregard.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.7. Do you experience any conflict, or dilution of normal cues when utilizing the flare line for either flare initiation or for control of trajectory to touchdown?

Subject	Remarks
1	I usually looked through the HUD then.
2	No, but does not require concentration on peripheral vision in last few feet of flare.
3	I think in this airplane there is a last instant conflict before touchdown for nice landings because a slight lowering of the nose is needed but flare line "holds" nose up.
4	Tended to not see the flare line.
5	Flare line is effective up to the flightpath symbol, then it gets masked with other clutter which implies external awareness.
6	No, but use of flare line resulted in firmer touchdowns.
7	No.
8	Flare line sometimes gets lost in clutter, particularly behind airspeed and altitude. Suggest improved prominence of flare line.
9	Yes - flare line tends to cause tunnel vision.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.8. Does use of the flare line interfere with lateral-directional control *in the flare?*

Subject	Remarks
1	No comment.
2	No but must concentrate on peripheral vision.
3	No.
4	Tended to not even see the flare line.
5	Yes it can.
6	No - in fact improves bank angle reference.
7	No comment.
8	No.
9	Yes. But I believe this is due to overdependence on the flare command.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.9. Please add any additional observations you might have regarding the adequacy of the head-up display in the final ILS approach and landing.

Subject	Remarks
1	No comment.
2	No comment.
3	The precision is fantastic. I noticed a slight tendency for a non-divergent lateral PIO due to this tightness. Longitudinal is nice.
4	The big advantage of the HUD is the integration of all necessary elements of control into a single display. With the present display there is the potential for "losing it" because of clutter and biases, but these could be improved. In airmass, better gyros should be used to avoid discrepancies.
5	In spite of many HUD advantages, this present system creates additional workload which would be unacceptable for airline operation.
6	Outer and middle marker inadequate.
7	High workload. Very difficult to get a handle on the *situation*. No instant cue as to what to do. Seems like you have to stop and think of one thing at a time.
8	HUD is used like a flight director but flight director symbology is much better. Obviously, HUD has heads up advantage which is considerable.
9	None.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach

QUESTION: III.A.10. Did you use the head-up display in the go-around maneuver? If so, did it present any special advantages or difficulties?

Subject	Remarks
1	Yes. I flew flightpath and potential flightpath to fly constant speed climb out. Great.
2	Did not use.
3	Yes. I am not convinced that flightpath symbol should change.
4	I thought it was helpful. You could tell at a glance whether your pitch attitude was correct.
5	Yes. Additional cues of positive climb gradient, *i.e.*, potential gamma and actual gamma. In TOGA mode, suggest flashing the potential gamma symbol whenever it is negative.
6	Yes. Advantages are head outside, speed control with potential gamma, and improved attitude. Use of alternate symbology during go-around was distracting.
7	Yes. I didnot appreciate all I was seeing. I tended to be depressed in seat from "g" and lost some cues. Did not like switching flightpath symbology.
8	Yes. HUD disadvantageous. Pitch ladder used for heading reference. Airplane pitch attitude controlled initially with boresight and 15^{o} mark. Suggest increase prominence of a go-around pitch attitude target. Used potential gamma and gamma to control pitch after initial rotation.
9	Yes. It provides the opportunity to get maximum performance from the aircraft not possible using the head down displays.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of ILS Approach
QUESTION: III.A.11. Would greater familiarity with the goaround use of the display have been helpful?

Subject	Remarks
1	No.
2	No.
3	No.
4	No.
5	It was adequately demonstrated.
6	Yes. We didn't discuss it much.
7	Yes.
8	No comment.
9	Yes.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of Localizer-only Approach

QUESTION: III.B.1.a. In comparison with conventional systmes, comment on the contributions or problems introduced by the head-up display in regard to: evaluation of visibility conditions while maintaining desired flight conditions.

Subject	Remarks
1	No comment.
2	Visibility was CAVU on all flights. I believe it would facilitate the ability to ascertain a more realistic outside cue than when head down.
3	Very much better.
4	No problems. Not having to scan into cockpit is a big contribution to HUD.
5	HUD better.
6	Very much better.
7	No comment.
8	Could assess visibility conditions using peripheral vision while using central vision in HUD to control flightpath.
9	Contributes in that there is no head down to head up to see outside.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of Localizer-only Approach

QUESTION: III.B.1.b. In comparison with conventional systems, comment on the contributions or problems introduced by the head-up display in regard to: determination of the initiation of descent from MDA (use of -3^{o} dots to evaluate position relative to 3^{o} glidepath.)

Subject	Remarks
1	INS was great. Airmass kept me .5 to 1.5 dots low on raw data glideslope.
2	Very effective when no VASI and way out on a long straight in (hazy or black hole).
3	Very much better.
4	Very helpful.
5	Much better.
6	Very much better.
7	No comment.
8	Difficult to judge when 3^{o} marks were coincident with touchdown zone. Dots were too far to each side. Suggest one more dot each side inboard of those provided.
9	Excellent addition - provides the appropriate point in space to begin descent on a desire flightpath.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of Localizer-only Approach
QUESTION: III.B.1.c. In comparison with conventional systems, comment on the contributions or problems introduced by the head-up display in regard to: maintenance of desired flightpath and speed to flare in nominal conditions and turbulence or shears.

Subject	Remarks
1	Excellent in INS. Poor in airmass.
2	Very much better - less workload.
3	Very much better.
4	No problems.
5	HUD much better in nominal conditions and not observed in shears.
6	Very much better.
7	No comment.
8	Similar to but somewhat higher workload than VASI. Did not observe shears.
9	Provides postive slot throughout the approach. Flown only in nominal conditions.

HUD QUESTIONNAIRE : GENERAL

SEGMENT : Approach - Visual Segment of Localizer-only Approach

QUESTION: III.B.2. Please add any additional observations you might have regarding the display in the localizer only approach.

Subject	Remarks
1	Localizer capture is confusing. *If it worked the way it is supposed to it seems like it would be very simple.*
2	Last half of approach after visual contact with runway is more precisely flown if 3° dots are placed on touchdown area and flown to that point.
3	Very much better.
4	None.
5	No comment.
6	No comment.
7	No comment.
8	No comment.
9	Could use vertical speed reference for non-precision approach.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION :1.a. Please comment on the two modes in relation to performance in crosswinds.

Subject	Remarks
1	Based on simulator results only, INS very much better. A great deal of interpretation required in airmass.
2	Airmass very much worse.
3	Airmass mode completely unsatisfactory. The desirable features for the INS mode were (1) no flightpath symbol offset for crosswind in VMC mode, and (2) "pseudo" flight director characteristics IMC (ILS, LOC, etc.) and VMC. I understand these can be incorporated in airmass mode.
4	INS much better. Separation between flightpath symbol and ILS information made it very difficult to control gamma.
5	Not observed.
6	Airmass very much worse. Pilot was forced to sample various wind drift correction angles which increased workload and decreased accuracy. Airmass presented confusing info at times.
7	Approaches were made in 20° crosswinds at 14 kts. Had trouble interpreting what was going on and how to track localizer. Had trouble looking at gamma, ILS circle and course line.Never felt comfortable that I had locked crab angle down. Mental workload of interpretation of situation too high.
8	Not observed.
9	Airmass very much worse. Heading slew function during ILS approach with crosswind is unacceptable. Displaced heading and gamma symbols from localizer course is too difficult to sort out for proper corrections.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 1.b. Please comment on the two modes in relation to performance in vertical wind shear conditions.

Subject	Remarks
1	Performed in simulator. INS better, because less interpretation required. Easier to detect shear and plug in correction.
2	Airmass better for shear. INS very much better.
3	See question 4.
4	Didn't see.
5	Not observed.
6	Not specifically observed.
7	Not observed.
8	Not observed.
9	Not observed.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 1.c. Please comment on the two modes in relation to performance of the flightpath symbol in acquiring and maintaining localizer centerline.

Subject	Remarks
1	INS better except with no wind where they are the same.
2	Airmass very difficult. INS relatively easy.
3	See question 4.
4	INS much better.
5	Airmass very much worse.
6	Much poorer performance in airmass mode due at times to confusion in symbology, specifically runway symbology and raw data localizer.
7	Would have preferred head down under IMC to airmass HUD.
8	No problem with either mode in nominal weather conditions experienced. Sometimes used the same technique for inertial as required for airmass - placed the flightpath symbol outside the localizer error symbol to increase gain of reducing localizer error.
9	Localizer intercept difficult in both modes due to incorrect mechanization. Maintaining centerline extremely difficult in airmass due to displacement of heading and gamma symbols.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION :1.d. Please comment on the two modes in relation to presentation and interpretation of required drift corrections.

Subject	Remarks
1	INS very much better. Airmass tougher than raw data.
2	INS - very easy.
3	See question 4.
4	INS much better.
5	Airmass much worse.
6	Airmass very much worse. Much confusion and poorer tracking. Never a doubt in INS.
7	Did not have time to look at drift correction on pitch symbol much as workload high. Did not feel I had drift correction nailed down especially at MDA.
8	No difference observed.
9	Due to offset of gamma and heading symbols, no way to determine what drift corrections, if any, were made in airmass mode.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 1.e. Please comment on the two modes in relation to accuracy of presented drift corrections.

Subject	Remarks
1	Once pilot figures out the drift in airmass and providing it remains stable, they are about same.
2	Once drift correction established with airmass, not much problem flying it.
3	See question 4.
4	Couldn't see any big difference. Main difference was in the lateral runway bias.
5	With present mechanization of slow inertial update rate and lag of drift angle, it is difficult to determine which system is more accurate in displaying drift.
6	Airmass very much worse.
7	No comment.
8	No difference observed.
9	Unknown.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 1.f. Please comment on the two modes in relation to vertical response of the flightpath symbol during climb, turns/banks, and level flight.

Subject	Remarks
1	Same.
2	Precession made task more difficult in airmass.
3	See question 4.
4	Couldn't see any big difference.
5	Airmass more active and horizon movement more noticeable.
6	Although airmass was worse during vertical response, it compared more favorably here than other tasks. Some anomalies noted in level flight commands during banks even in INS mode.
7	Airmass OK but felt I could do a better job maneuvering for intercept heads down.
8	No difference observed.
9	No difference noted.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 1.g. Please comment on the two modes in relation to ease of interpretation and usage.

Subject	Remarks
1	INS very much easier to interpret. Airmass might be easier after much practice but at first I would rather fly raw data.
2	INS - no problem. Airmass - difficult to establish the proper course alignment.
3	See question 4.
4	INS better as it is more one to one with outside world, especially flightpath symbol.
5	INS much better.
6	Airmass very much worse. Confusing and conflicting particularly when VMC.
7	Airmass very high workload, almost unacceptable.
8	No difference observed.
9	No problem interpreting but difficult to use the airmass mode.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 2. Compare the extent to which the airmass and the INS mode HUD aided you in executing approaches to minimums.

Subject	Remarks
1	Both make crosscheck easier. Both would require substantial training to become comfortable and proficient.
2	INS - very helpful - reduced workload and extremely accurate. Airmass - real problem.
3	See question 4.
4	Both did job. I had an S-turn PIO problem with INS and an interpretation problem with airmass.
5	Both systems have potential to aid the pilot. Present mechanization has serious/significant design deficiencies which add to present workload to an unacceptable degree.
6	INS flown comfortably both IMC and VMC to CAT II minimums. There were no comfortable approaches in airmass mode.
7	Both excellent for VFR approaches. Would need a lot of training to feel comfortable IMC.
8	Slightly higher workload in airmass.
9	Airmass less accurate than head down.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : With which mode did you feel most confident when executing low approaches?

Subject	Remarks
1	At MAP, they were about the same.
2	INS.
3	See question 4.
4	INS. Just not sure how big the airmass errors are.
5	INS. Greater ease in tracking and assessing approach progress.
6	INS.
7	INS. Workload much lower, not as much interpretation needed.
8	INS - because I was briefed on certain inertial advantages although in the nominal weather conditions experienced, these were not evident.
9	INS. Precise and accurate. Flightpath symbology correctly portrayed flightpath position in relation to real world.

HUD QUESTIONNAIRE : AIRMASS VS. INERTIAL

QUESTION : 4. Which mode do you prefer? Why?

Subject	Remarks
1	Definitely INS. Airmass requires a lot of interpretation.
2	INS.
3	Airmass in this installation completely unsatisfactory. I understand that most of the desirable features in the INS mode for this installation can be incorporated in the airmass mode. They should be.
4	INS.
5	INS - better platform, less precession, greater accuracy, less workload.
6	INS overwhelmingly because of the smoothness, accuracy and lack of conflicting symbology. In airmass mode, the display was more unstable, less accurate and more confusiang and would probably not meet anyone's standards for operations in IMC. INS mode provided outstanding display.
7	INS - lower workload - more comfortable and gave you a better sense of confidence in the approach.
8	INS.
9	INS.

HUD QUESTIONNAIRE : FINAL

QUESTION : 1. Did you have any problems with the physical location of the Pilot Display Unit (e.g., interference with forward view, closeness, uncomfortable seat position, etc.)?

Subject	Remarks
1	Definitely yes - I had to sit too close to the yoke. PDU should be adjustable fore and aft.
2	Eyes tended to fixate on viewer. Had to make a concerted effort to look "through" viewer in outside scanning maneuver.
3	No. I was pleased to find that fixed eye markers in airplane put eyes in best position for outside, head down , and HUD.
4	No. Might have been slightly more comfortable if HUD was mounted aft just a little.
5	None whatsoever.
6	Yes. When positioned with eyes 6 inches behind and centered, I was much too close to the controls and too high. On subsequent flights I put seat in comfortable position relative to controls and leaned forward to observe HUD. This was found to be satisfactory.
7	Yes. Felt I was straining forward to see symbology. Location was not comfortable during approach. Depressed in seat on MA and lost half of HUD. Could not change heading or course select on HSI with HUD down. Made several approaches with HUD not completely down - BAD.
8	I used a seat position 1" to 2" forward of my normal 727 position. Had to stretch up or slouch down in seat to see entire display during gross maneuvering.
9	No comments.

HUD QUESTIONNAIRE : FINAL

QUESTION : 2. Please comment on the visual quality of the head-up display (e.g., brightness, distortion, clarity, jitter, etc.).

Subject	Remarks
1	Excellent in all light conditions.
2	If left too bright at night, distortion appears. Jitter is obvious in all flight regimes.
3	Brightness and clarity OK except for occasional distortion at bright setting. Rachety movement due to computation time.
4	Good except for some jitter in horizon, speed error, and potential gamma. Display very cluttered at times.
5	The brightness control should incorporate both manual and automatic compensation. Full manual bright causes distortion and saturation. Symbol size and clarity are adequate but symbol jitter is excessive. There was no obvious symbol distortion.
6	Overall, very good. There was some occasional jitter but at an acceptable level. Clarity was good but some of the numbers would be easier to read if they were smaller. Display was good even with sun directly centered in HUD and with sun shield in place.
7	Brightness good for all conditions including sun and night. 3° depression line lower intensity than other symbology - hard to see when others at right intensity. Lost some references in bright lights of town. Flying gamma on horizon - gamma,A/S,alt.,heading all blend together and is confusing.
8	There was excessive jitter but I learned to disregard it. At dusk, I needed to adjust brightness as heading changed toward and away from sun. Need better location for brilliance control.
9	No comments.

HUD QUESTIONNAIRE : FINAL

QUESTION : Did you experience any eye discomfort?

Subject	Remarks
1	No.
2	No.
3	No. Preferred white display in simulator over green in airplane.
4	No.
5	Yes, due primarily to symbol jitter and excessive symbol clutter and overlay during IMC approaches (e.g., runway, gamma, and ILS dot can overlay and thus reduce conspicuity of separate symbols.)
6	No.
7	No.
8	No.
9	No comments.

HUD QUESTIONNAIRE : FINAL

QUESTION : 4. Did you notice and tendency to fixate on any elements of the display to the exclusion of other elements or the real world scene?

Subject	Remarks
1	At first yes but very easy to overcome.
2	First few approaches tended to fixate on gamma symbology and runway symbol. Had to concentrate to look through to real world.
3	No. However, I did fix on total display to exclusion of realworld scene until I needed world, as in close in final.
4	Yes. I was concentrating on not missing the MDA reference on a night Localizer approach and it was not set. I flew 100 - 200 feet below MDA.
5	Initially fixed on a slightly overactive potential flightpath symbol. During IMC evaluation, I tended to fixate on a very overactive glideslope or localizer aim dot.
6	Yes, but tendency was reduced with experience. On the last flight I was able to notice other aircraft while looking at the display. Greatest tendency to fixate is while flying ILS approach.
7	Yes, especially during IMC approach. Fixate on gamma and ILS dot. Did not see DME readout. Tended to concentrate on above and airspeed to the exclusion of altitude.
8	Had tendency to fixate on display as a whole to exclusion of forward real world scene.
9	No comments.

HUD QUESTIONNAIRE : FINAL

QUESTION : 5. Were you able to take your attention away from the display and return it comfortably?

Subject	Remarks
1	Yes.
2	Yes.
3	Yes. I sneaked peeks at IVSI when using HUD without potential flightpath symbol.
4	Yes.
5	Generally yes on a no load, no stress situation. With turbulence, shears, localizer or glide-slope deviation full pilot attention will be required.
6	Yes.
7	Yes.
8	Yes.
9	No comments.

HUD QUESTIONNAIRE : FINAL

QUESTION :6. Did you notice any tendency for the display symbology to mask or obscure necessary outside cues such as approach lights, runway lights, markings, or other aircraft for collision avoidance?

Subject	Remarks
1	During night landings from initiation of flare to touchdown.
2	No.
3	No.
4	Copilot spotted traffic that I had missed through the display up and away once. Brightness of display may obscure touchdown zone at night slightly.
5	Yes. There is too much information displayed both above and below DH. One symbol can mask another. Requires more pilot attention to symbol discrimination to the exclusion of external cues.
6	At night in the flare mode, the display masked the runway environment. Use of de-clutter was necessary. No problem during day flight.
7	Collision avoidance a problem in terminal area. Good exercise during night VFR approaches at Stockton as there were numerous aircraft which could only be seen by looking around HUD. Could not pick them up through HUD. Flare command picked up readily but gets lost when it reaches gamma.
8	No problem with display obscuring larger outside cues such as horizon, runway, etc. I think the display, particularly the edges, would obscure other aircraft (which are quite small angularly) to the detriment of collision and avoidance.
9	No comments.

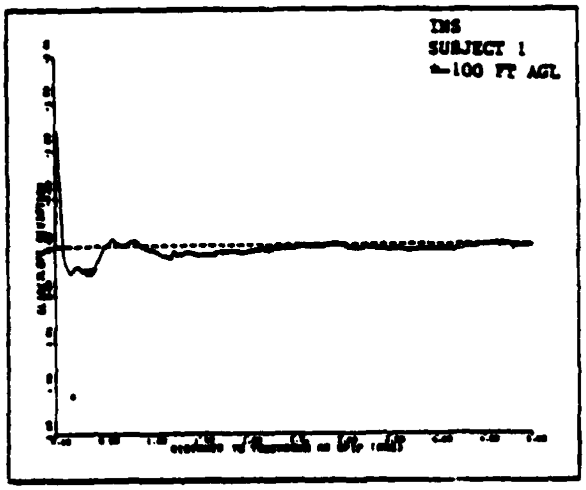
HUD QUESTIONNAIRE : FINAL

QUESTION : 7. Please list any questions you might have regarding the usefulness of this head-up display that have not been addressed in this program.

Subject	Remarks
1	No comments.
2	No comments.
3	Could possibly add limit thrust information.
4	How much training is required to prevent "losing" the display due to clutter?
5	No comments.
6	On my last flight I flew a PAR approach and found the HUD to be an outstanding display for this purpose. Reccommend further investigation.
7	No comments.
8	No comments.
9	No comments.

APPENDIX J

PLOTS OF GLIDE SLOPE AND LOCALIZER DEVIATIONS FOR INS AND AM REFERENCED HUD APPROACHES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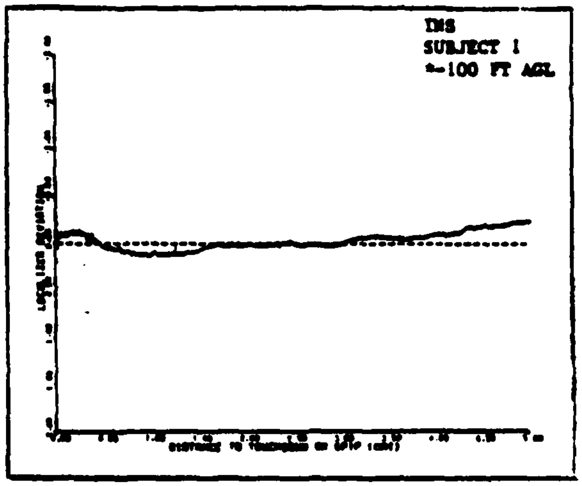
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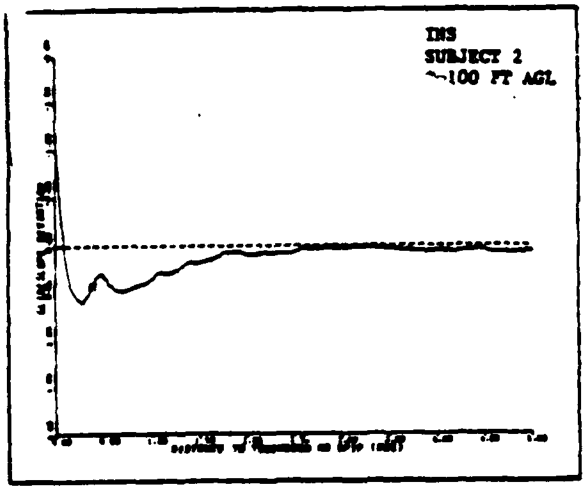
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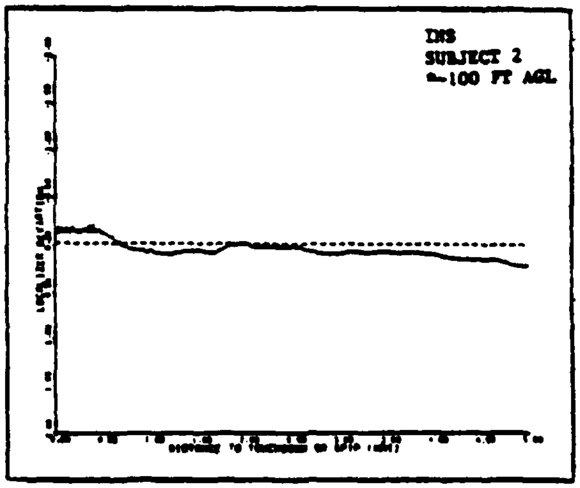
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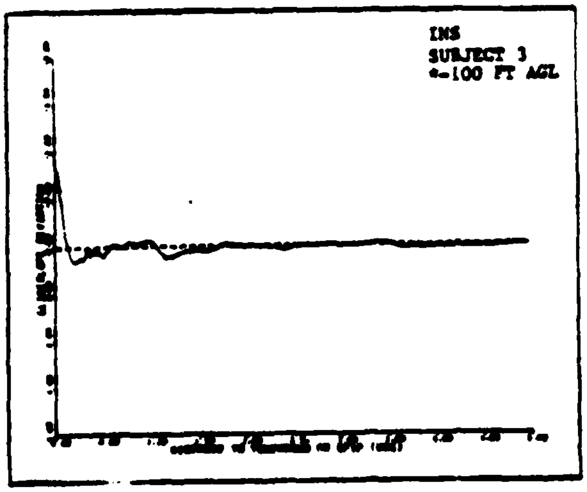
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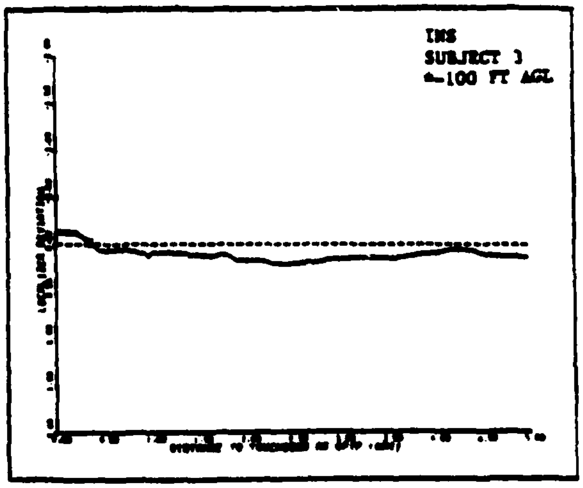
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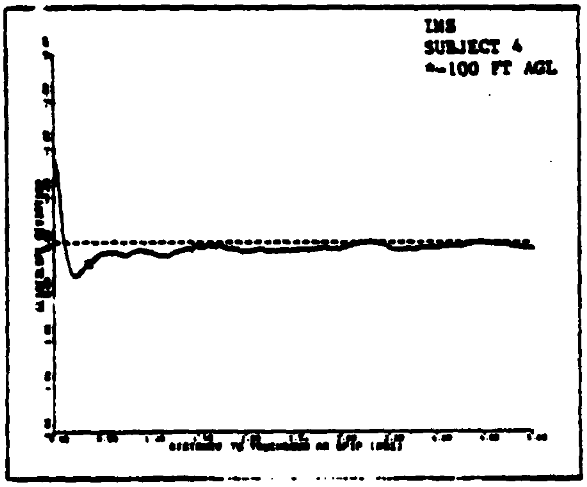
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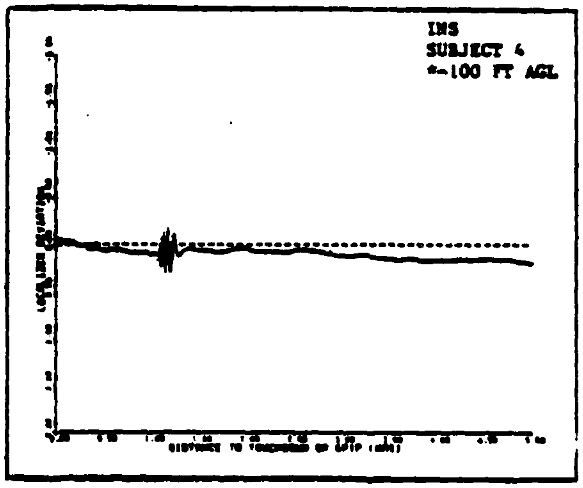
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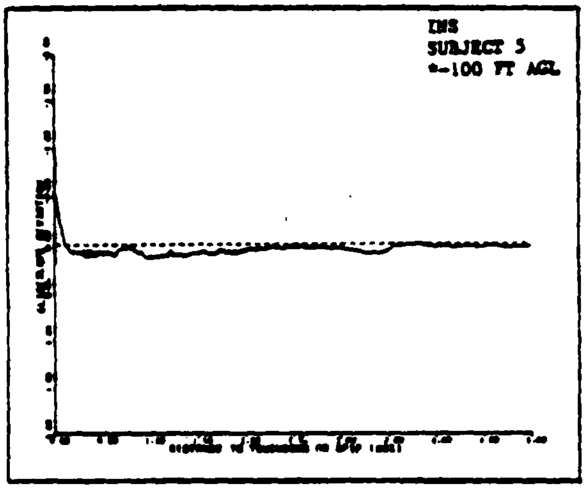
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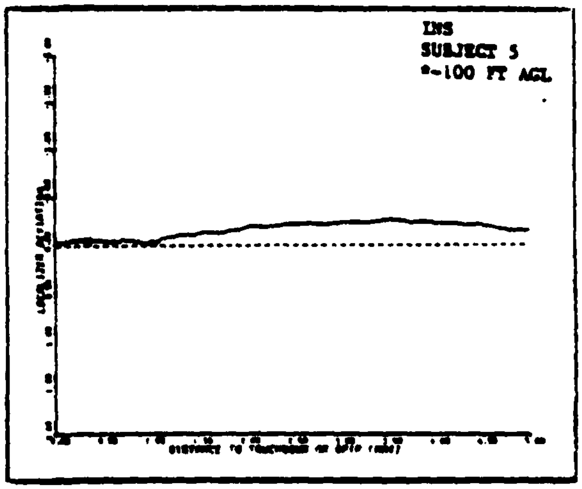
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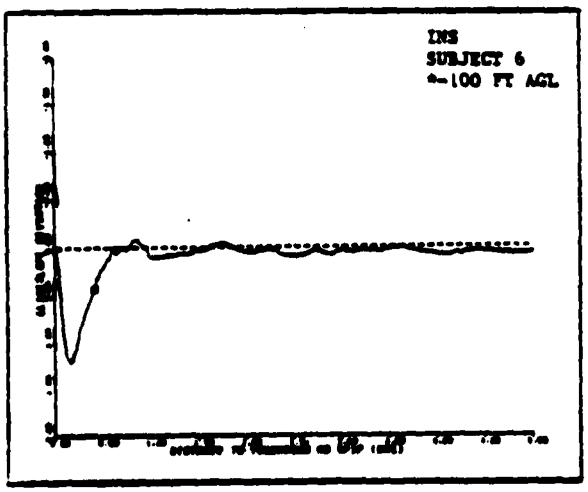
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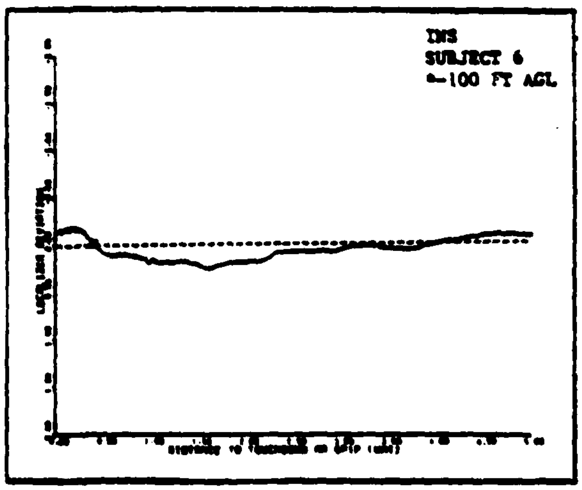
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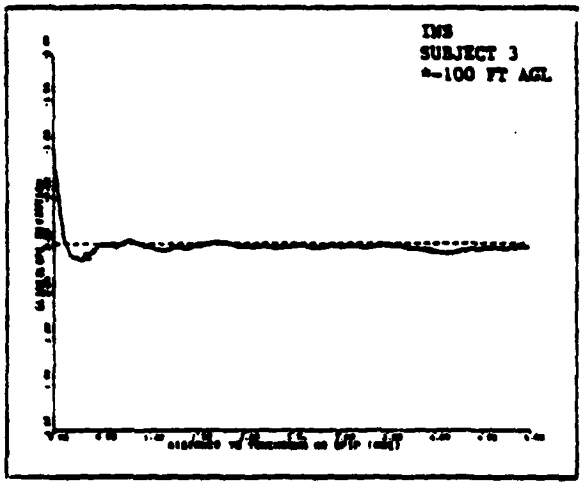
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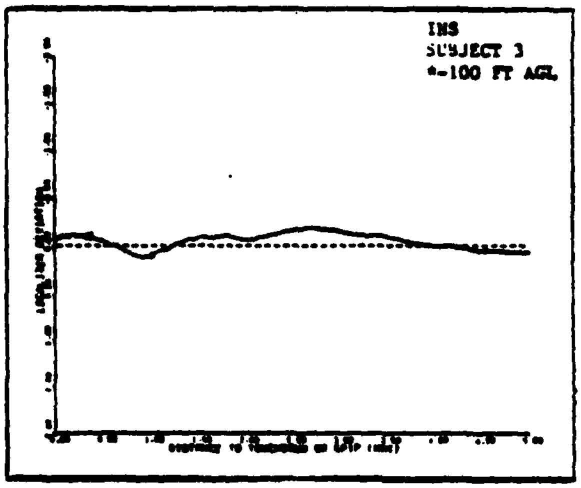
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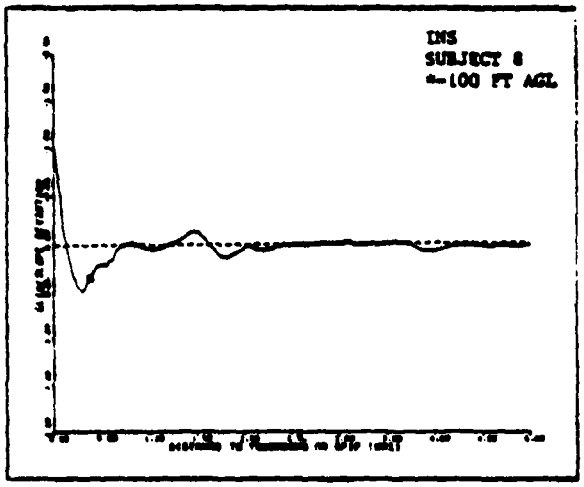
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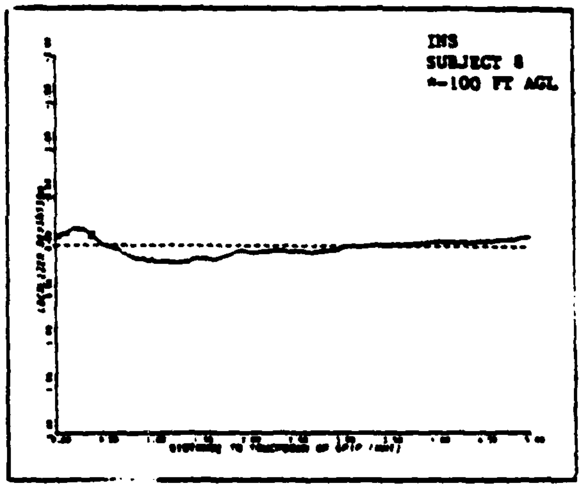
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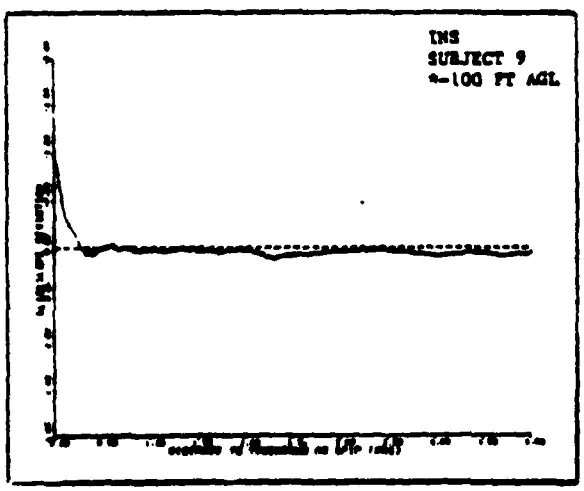
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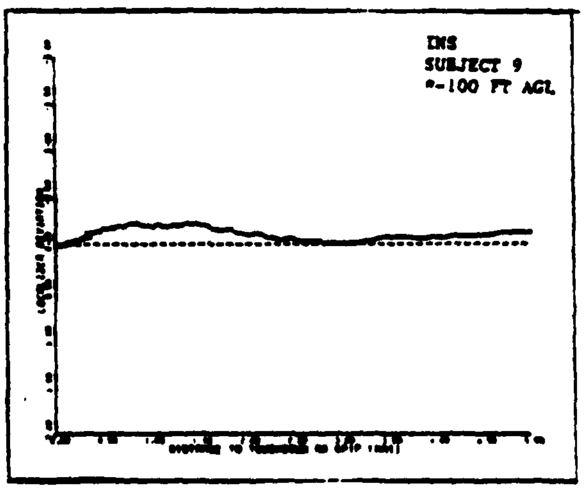
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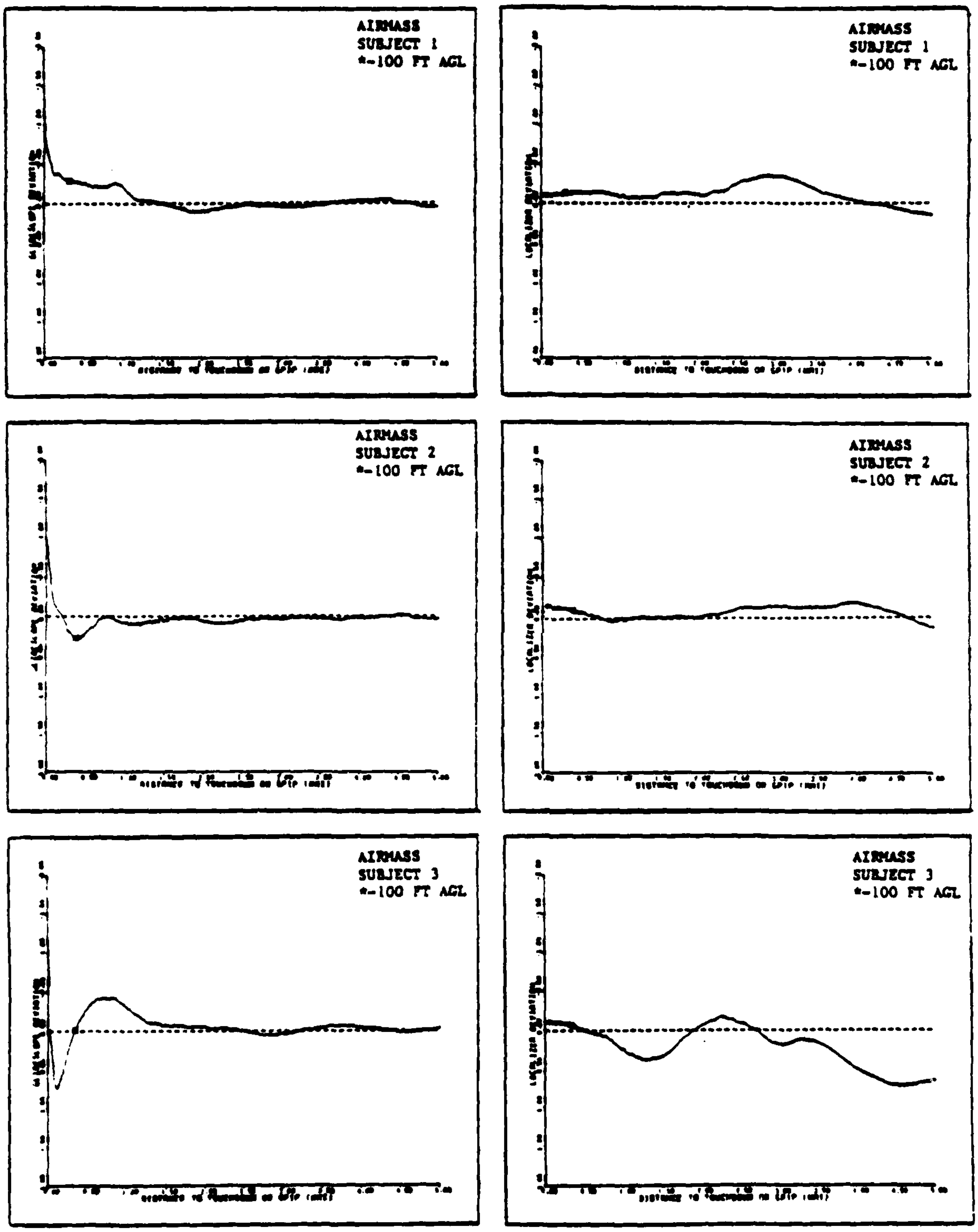
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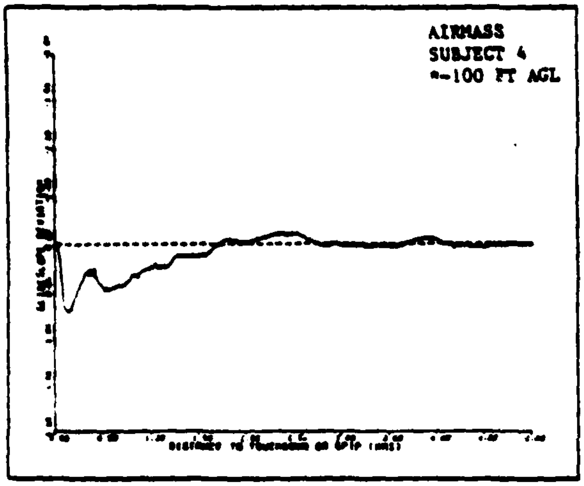
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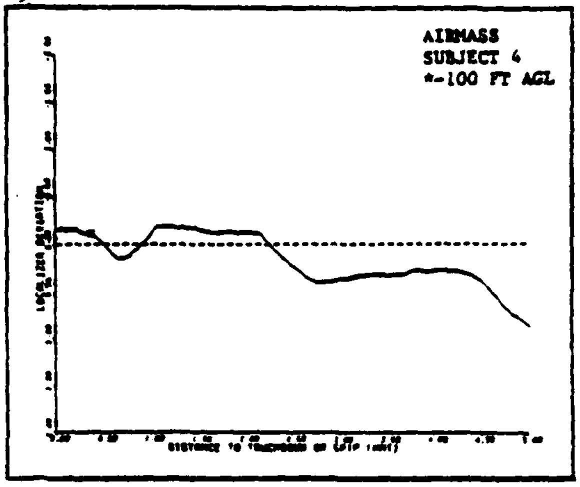
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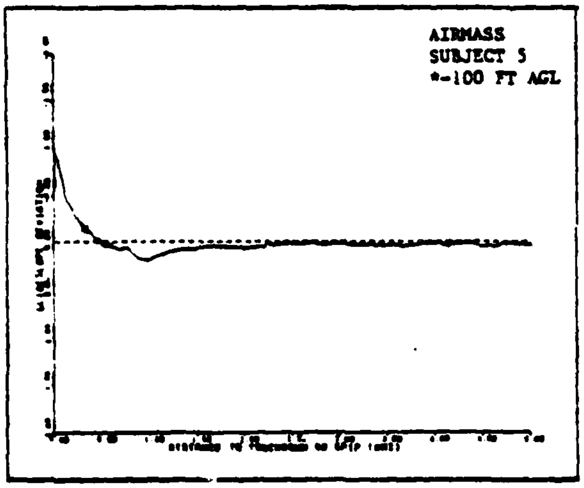
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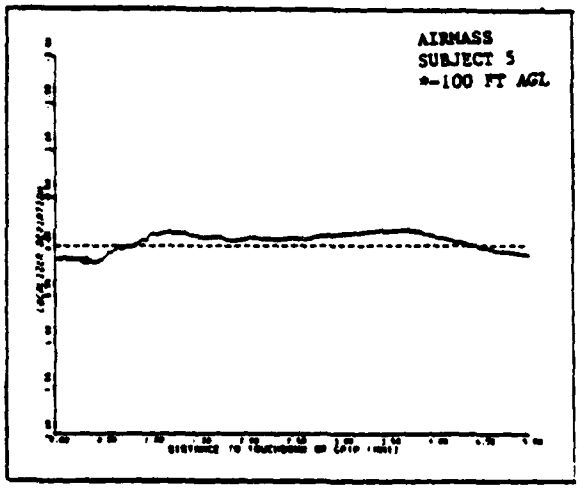
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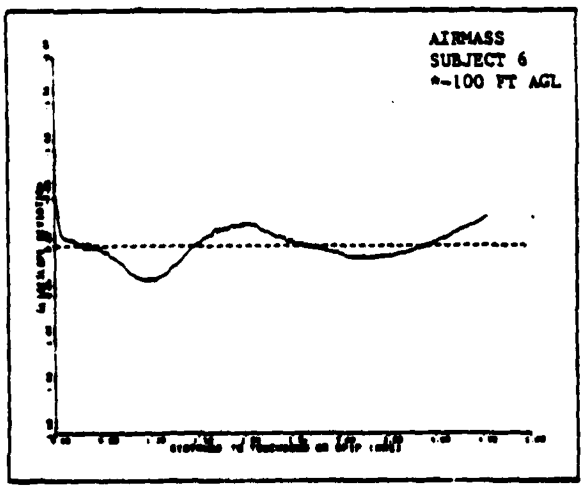
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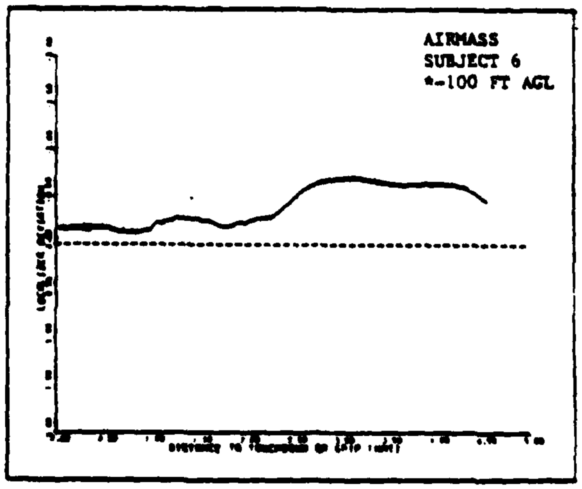
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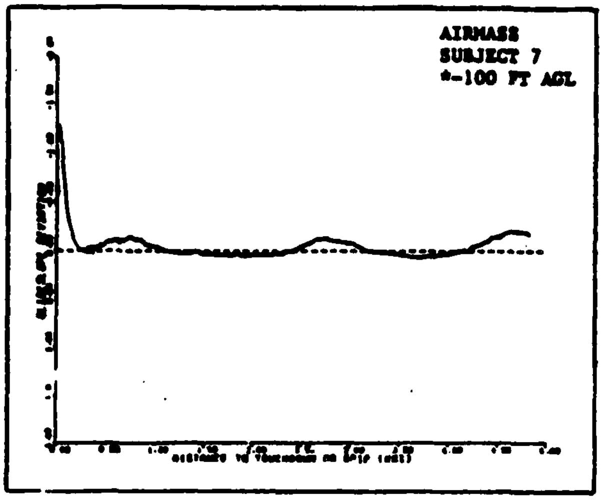

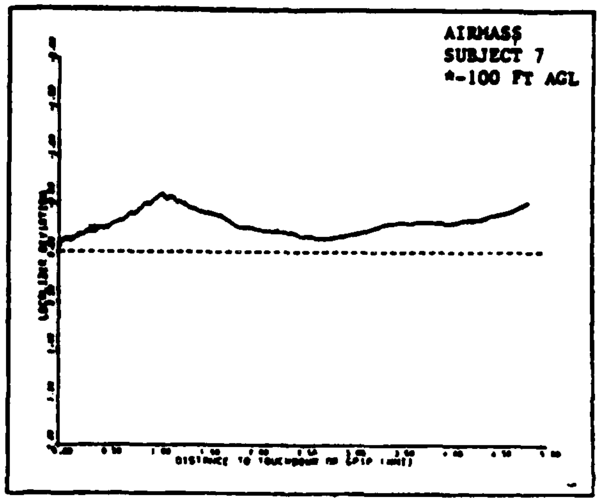

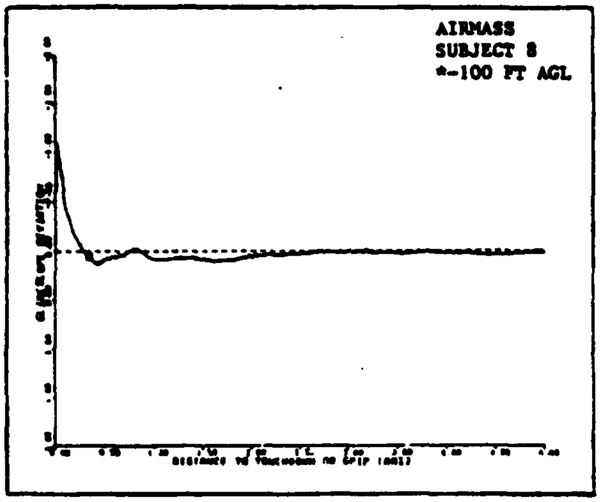

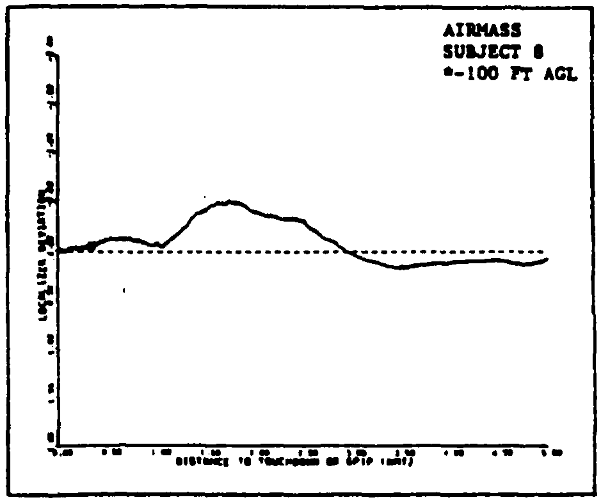

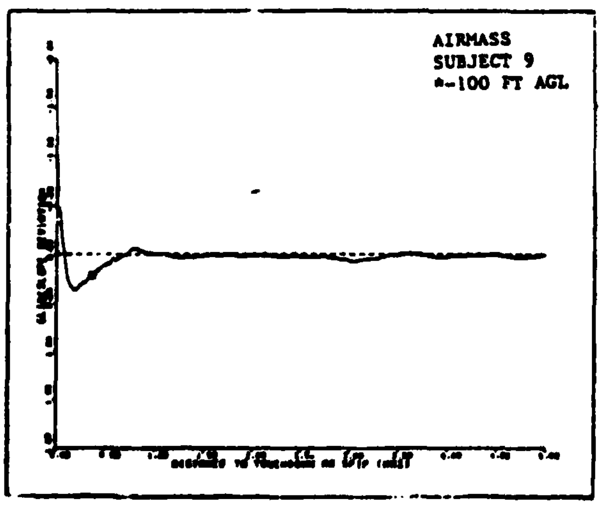

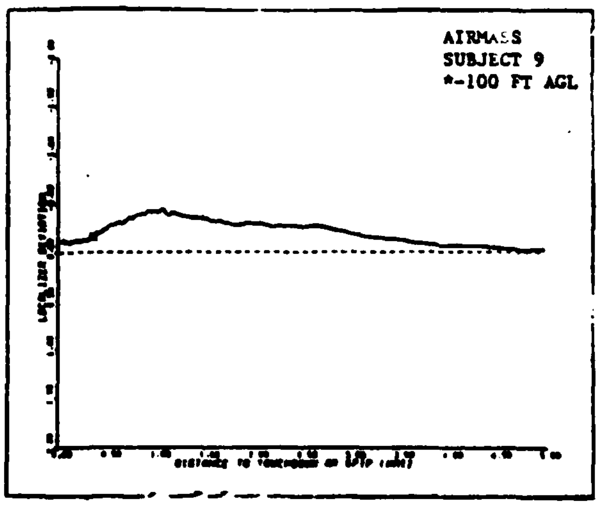

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